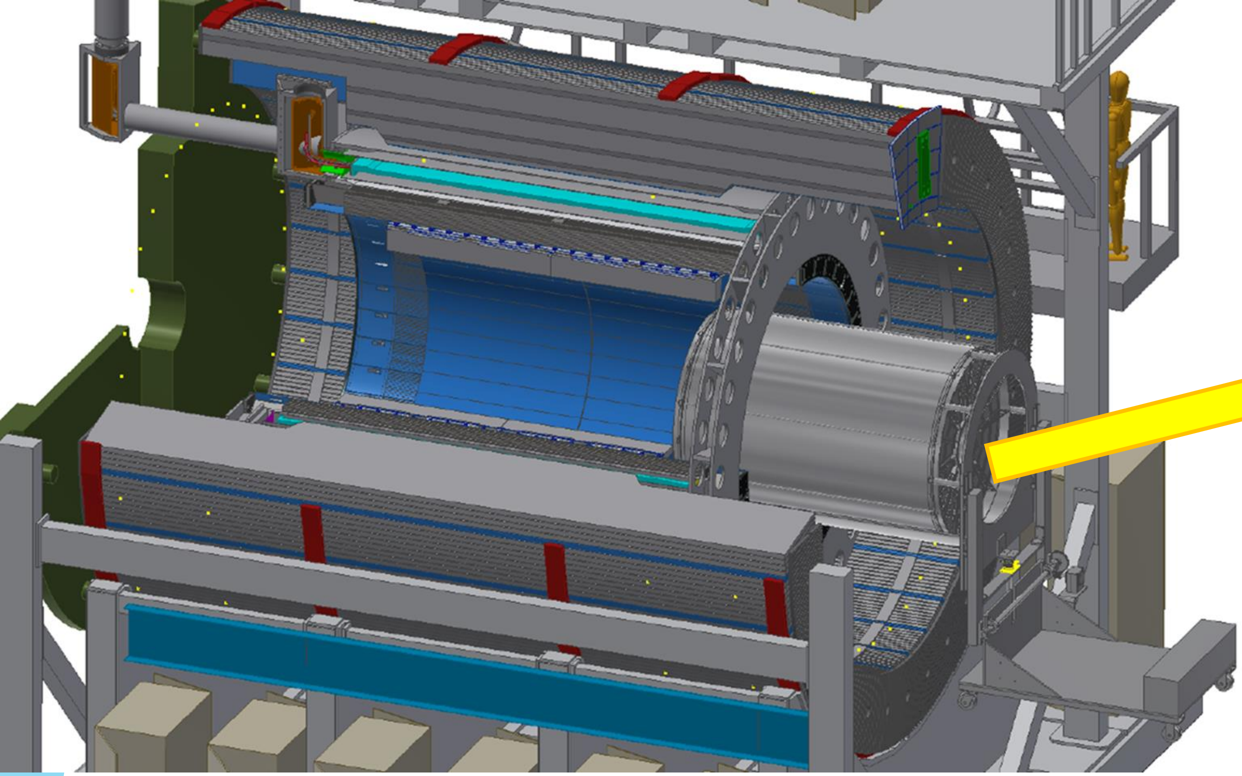
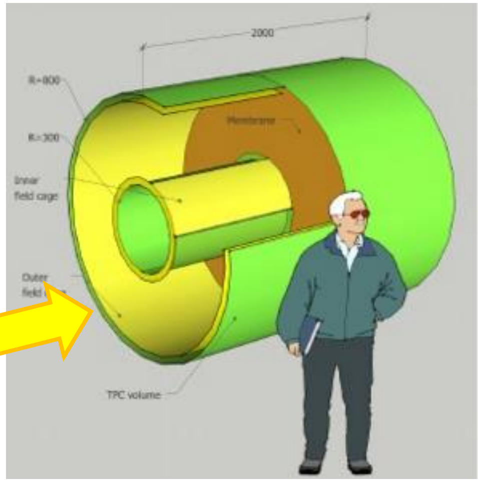
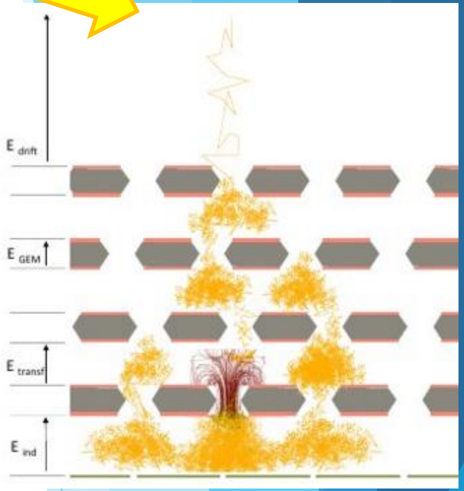
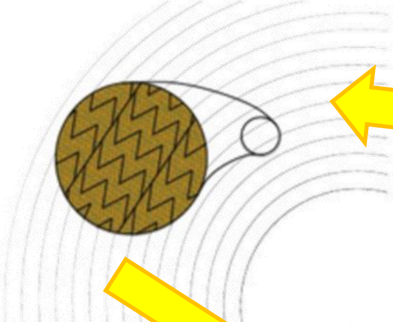


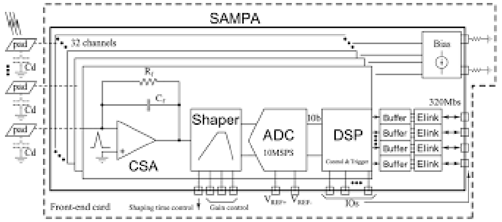






sPHENIX TPC Detector Overview

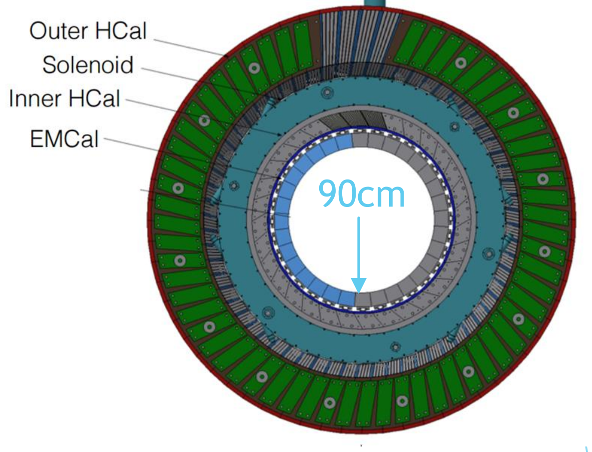
TK Hemmick



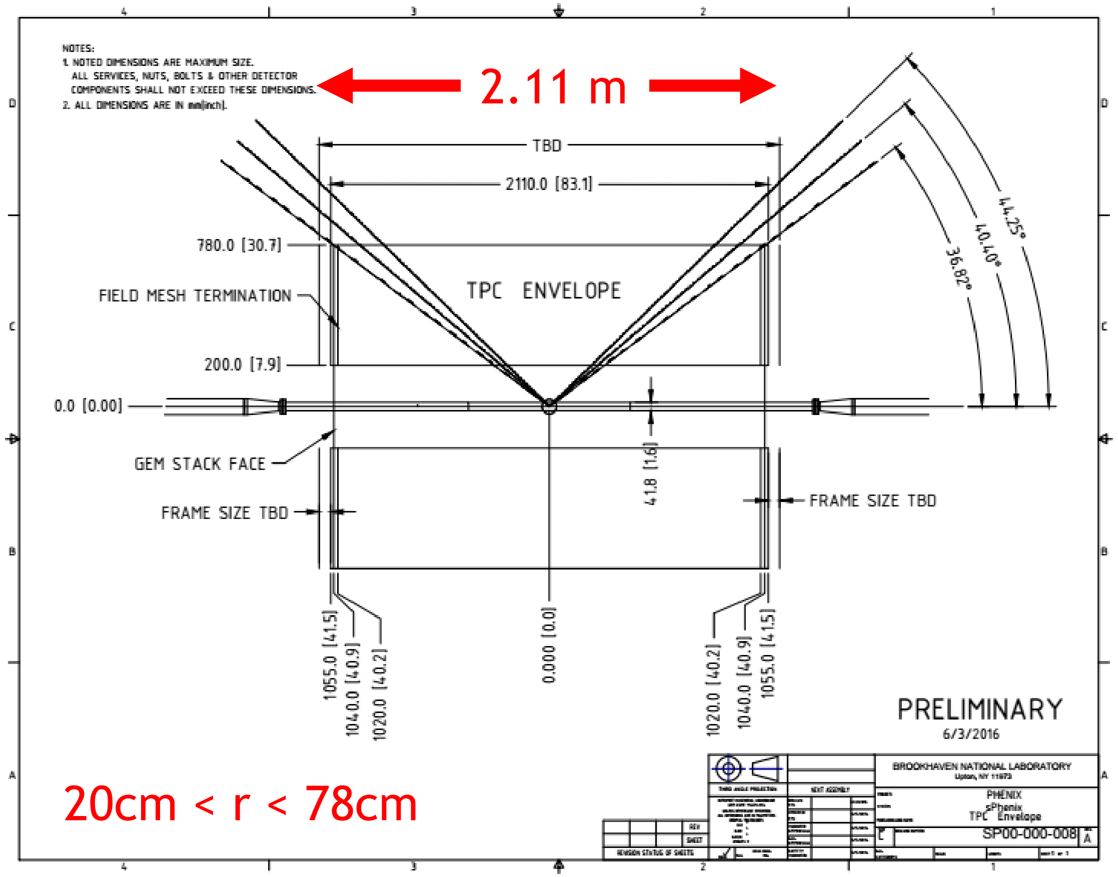
Technical Description

- Mechanical Constraints (magnet/EMCal-driven)
  - EMCal Mechanical constraint @ r=90cm.
  - $|\eta| < 1.1$ or $Length \approx Diameter$
- Physics program accomplished via two toughest constraints:
  - Mass resolution sufficient to resolve Upsilon States.
    - $\boldsymbol{\sigma_m < 100\ \frac{MeV}{c^2}\ @\ m \approx 9\ \frac{GeV}{c^2}}$ ← Drives $\sigma_{r\phi}$<250μm
- Environmental constraints:
  - Central Au+Au multiplicity @ full RHIC Energy.
  - Full RHIC-II Luminosity (50-100 kHz raw, 15 kHz w/in vertex)

Drives gateless TPC

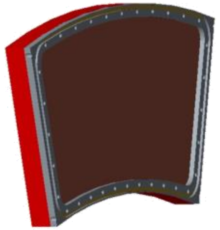


Mechanical Constraint



Project Scope

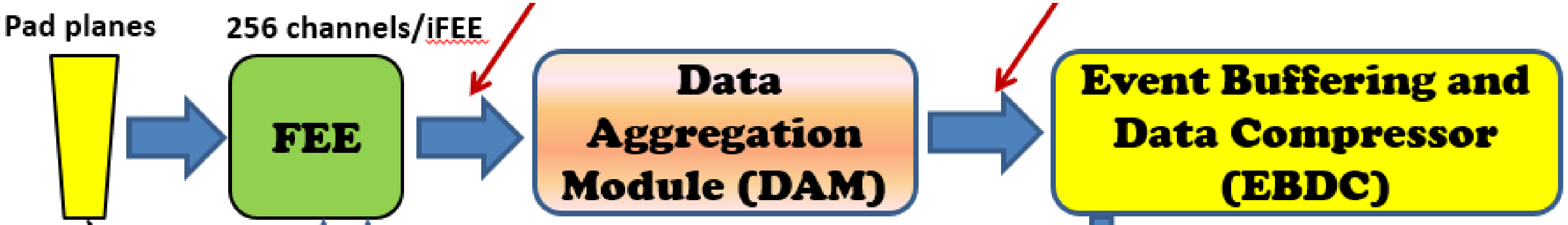
- Prototyping
  - v1 Field Cage: Full sized, designed to be usable if successful.
  - v1a/v1b modules: Investigations of segmentation, position linearity, IBF
  - v2 Field Cage: Full sized, intended for use in sPHENIX.
  - v2a/v2b/v2c modules: Design evolution toward final avalanche module, technology competition.
  - Pre-production: Test both the design of final modules and quality of facilities.
- Production
  - Modules produced in parallel at 3 facilities: PNPI/ Vanderbilt/ Weizmann Institute
  - Each facility produces 24+spares modules of a single size.



VANDERBILT UNIVERSITY

WEIZMANN INSTITUTE OF SCIENCE

- Electronics
  - FEE: on board card carrying SAMPA chip and FPGA with “light duty” (initialization, elink→8b/10b)
  - Data Aggregation Module (DAM): Collects 8 FEE and “clusters” across pads & time.
  - Event Builder Data Compressor: Interface between DAM and (eventually RCF), reduces data via compression.



High Level Schedule

	WBS	Task Name	Duration	Start	Finish
	1.3.2	Time Projection Chamber	1105 days	Thu 10/1/15	Wed 3/11/20
	1.3.2.1	TPC Prototyping	685 days	Thu 10/1/15	Fri 6/29/18
	1.3.2.1.1	TPC Prototype v1	490 days	Thu 10/1/15	Mon 9/18/17
	1.3.2.1.2	v1 Magnet Test (v1a module)	20 days	Thu 6/1/17	Wed 6/28/17
	1.3.2.1.3	v1 Performance Review	10 days	Tue 9/19/17	Mon 10/2/17
	1.3.2.1.4	TPC v1 Prototype Complete	0 days	Mon 10/2/17	Mon 10/2/17
	1.3.2.1.5	TPC Prototype v2	250 days	Tue 4/4/17	Thu 4/5/18
	1.3.2.1.6	Performance review v2 prototype	10 days	Fri 4/6/18	Thu 4/19/18
	1.3.2.1.7	TPC Prototype v2 Complete	0 days	Thu 4/19/18	Thu 4/19/18
	1.3.2.1.8	TPC Preproduction Prototype	164 days	Wed 11/1/17	Fri 6/29/18
	1.3.2.2	TPC Production	280 days	Wed 8/1/18	Fri 9/13/19
	1.3.2.2.1	TPC Module Production	280 days	Wed 8/1/18	Fri 9/13/19
	1.3.2.2.2	TPC Laser System	174 days	Wed 8/1/18	Fri 4/12/19
	1.3.2.2.3	TPC Gas System	230 days	Wed 8/1/18	Tue 7/2/19
	1.3.2.2.4	TPC Cooling System	202 days	Wed 8/1/18	Wed 5/22/19
	1.3.2.3	TPC Electronics	834 days	Tue 11/1/16	Wed 3/11/20
	1.3.2.3.1	TPC Frontend Electronics Card	817 days	Tue 11/1/16	Fri 2/14/20
	1.3.2.3.2	TPC Digital Aggregator Module	695 days	Tue 11/1/16	Fri 8/16/19
	1.3.2.3.3	TPC Event Buffering and Data Compressor Procurement	834 days	Tue 11/1/16	Wed 3/11/20

v1 prototype (LDRD & eRD6 funds)

v2 prototype (recent scope change)

Module Production phase

- July 2016: TPC Mechanics Cost & Schedule Mini Review.
- We have implemented 43/47 recommended updates to the MS Project File.
- Highest Level Updates include:
  - Capture of the v1 prototyping effort (off project funds).
  - Change scope of v2 work to include complete 2nd prototype field cage.
  - Capture costs of facility preparation for module production phase.
  - Captures the cost of a technician working for US in the CERN GEM shop.

Mechanical Design 1

- Traditionally TPCs are considered as slow devices:
  - Long time to drift the primary electrons to the gain stage.
  - LONGER time to dump the positive ions down the drain.
- New concepts coming out of ALICE and STAR experience.
  - “Stacked” events are not so big problem (STAR and ALICE):
  - Ion field distortion is a “manageable” correction (STAR)
  - New device (ALICE):
    - Gate-less design using gain stage w/ intrinsically low Ion Back Flow (IBF).
    - Continuous readout electronics (define event boundaries offline).

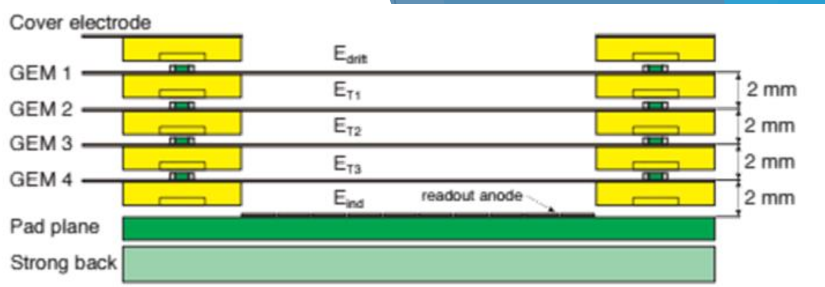
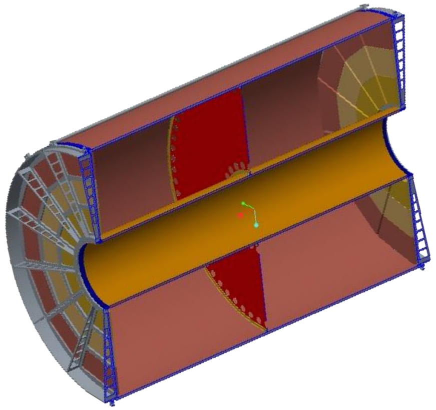
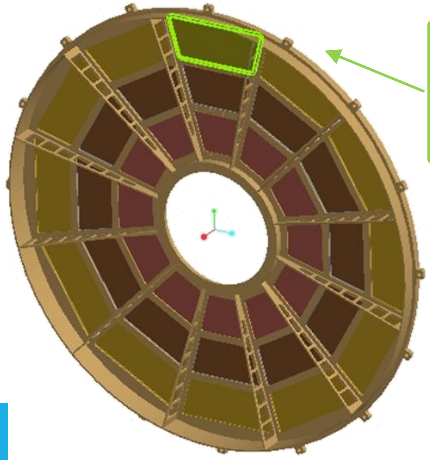


Figure 4.6: Schematic exploded cross section of the GEM stack. Each GEM foil is glued onto a 2 mm thick support frame defining the gap. The designations of the GEM foils and electric fields used in this TDR are also given. E_{drift} corresponds to the drift field, E_{T_i} denote the transfer fields between GEM foils, and E_{ind} the induction field between the fourth GEM and the pad plane. The readout anode (see Eq. (4.2)) is indicated as well. The drift cathode is defined by the drift electrode not shown on this schematic.

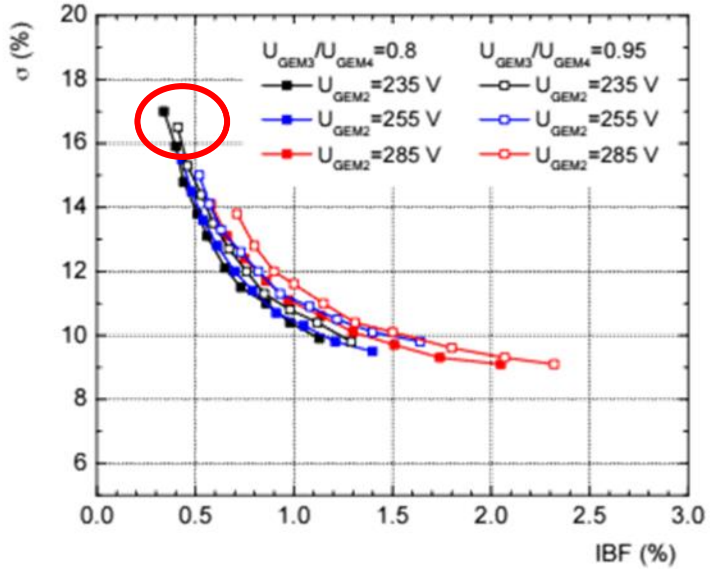
Micro Pattern Gas Detector

SAMPA Chip





12 in ϕ
3 in r

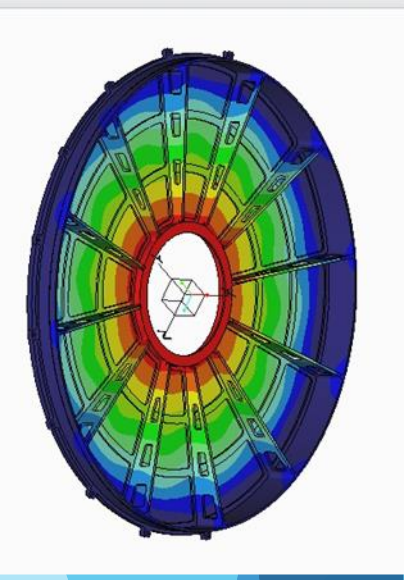


Effectively a STAR/ILC-like field cage coupled to an ALICE-like avalanche stage

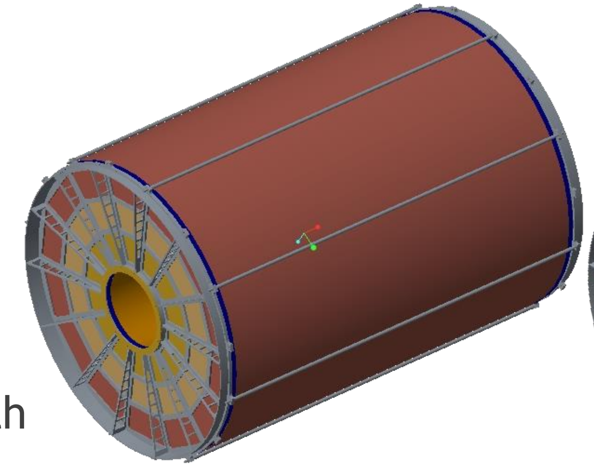
Mechanical Design 2

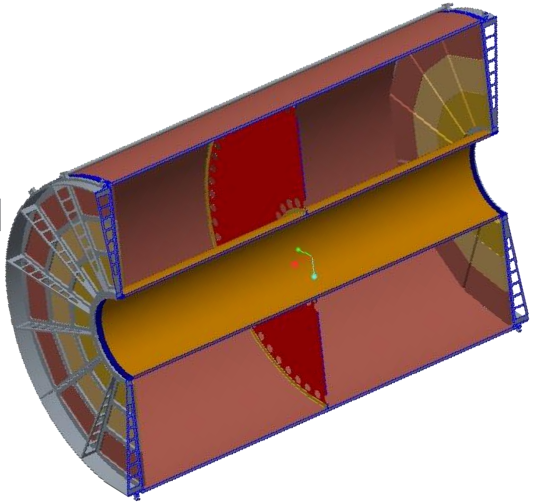
NOTE: Table is just M&S

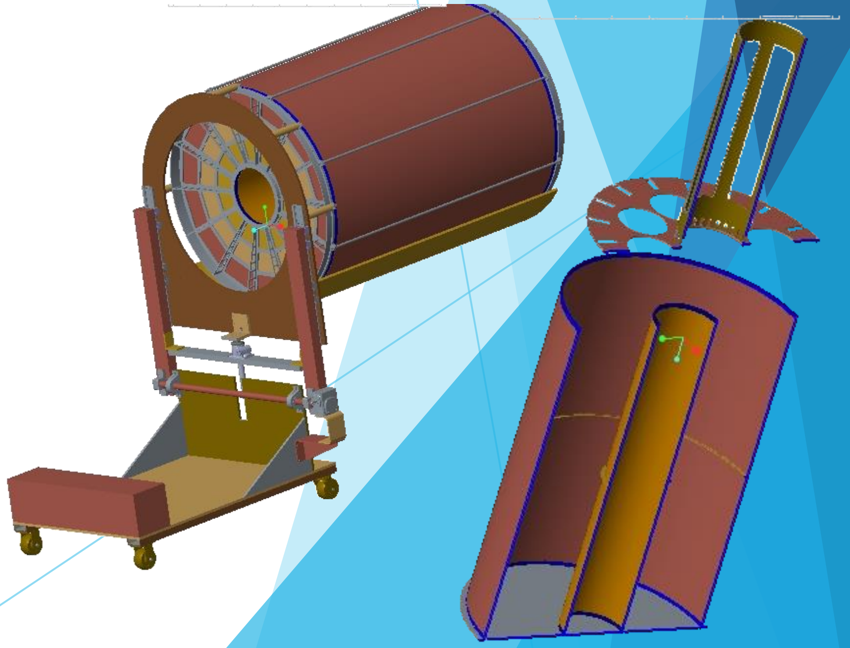
Outer Barrel	Honeycomb	Plascorp	4	6	270.18	$1,621.08	ORDERED		
	Striped circuit cards	All-flex	5	8	2925	$23,400.00	Pending	Manufacturer Quote	
	3 mil kapton 44" x 108 LF	Dunmore	2	3	7260	$21,780.00	Pending	Manufacturer Quote	
	3 mil kapton 22" x 108 LF	Dunmore	4	5	4070	$20,350.00	Pending	Manufacturer Quote	
	FR4 outer sheets 4' x 4'	ePlastics	8	10	114.58	$1,145.80	Pending	Manufacturer Quote	
	HVPW resistors	DigiKey	800	1000	1.17	$1,170.00	Pending	Manufacturer Quote	
	High Voltage Cable	Dielectric Sciences				$600.00	Pending	Web Search	$70,066.88
Inner Barrel	Striped circuit cards	All-flex	5	8	1500	$12,000.00	Pending	Manufacturer Quote	
	3 mil kapton 44" x 108 LF	Dunmore	1	1	7260	$7,260.00	Pending	Manufacturer Quote	
	3 mil kapton 44" x 108 LF	Dunmore	1	2	4070	$8,140.00	Pending	Manufacturer Quote	
	FR4 Sheets 4' x 4'	ePlastics	2	2	114.58	$229.16	Pending	Manufacturer Quote	
	HVPW Resistors	DigiKey	800	1000	1.17	$1,170.00	Pending	Manufacturer Quote	$28,799.16
Other	Central Membrane					$8,000.00		Experience	$8,000.00
	End Caps					$20,000.00		Experience	$20,000.00



- Space frame endcap ala ILC
- 3 radial segments to improve reliability
- 12 segments in azimuth

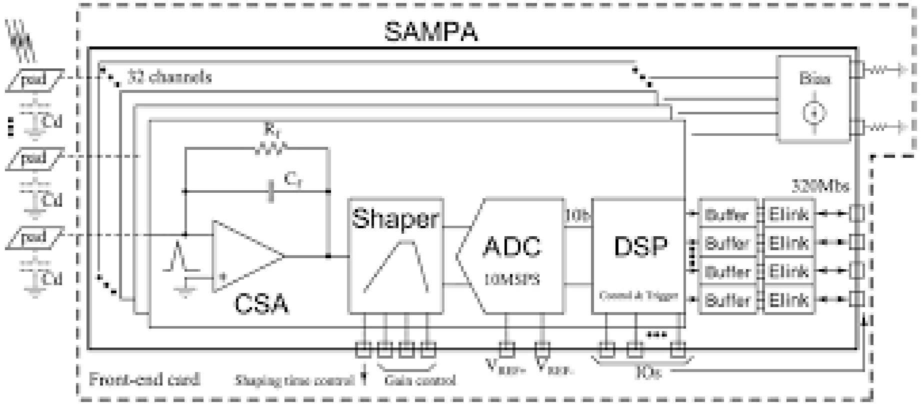






John Brodowski (BNL) -- TPC Engineer

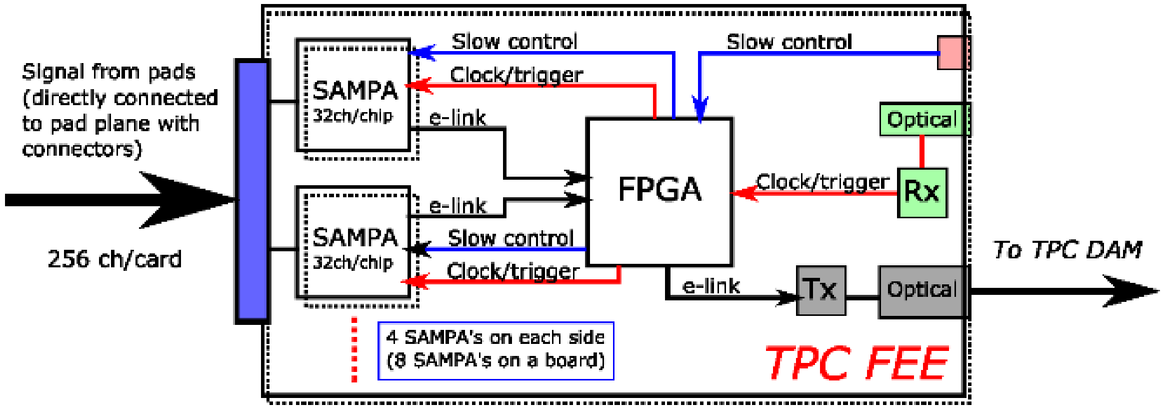
Electronics Design 1



- SAMPA chip developed for ALICE.
- Commonality:
  - Neon-based gas mixture.
  - Quad-GEM avalanche stage.
  - Signal polarity!
- SAMPA planned for use in STAR.
- Our needs most closely resemble STAR, but still require slight mods.

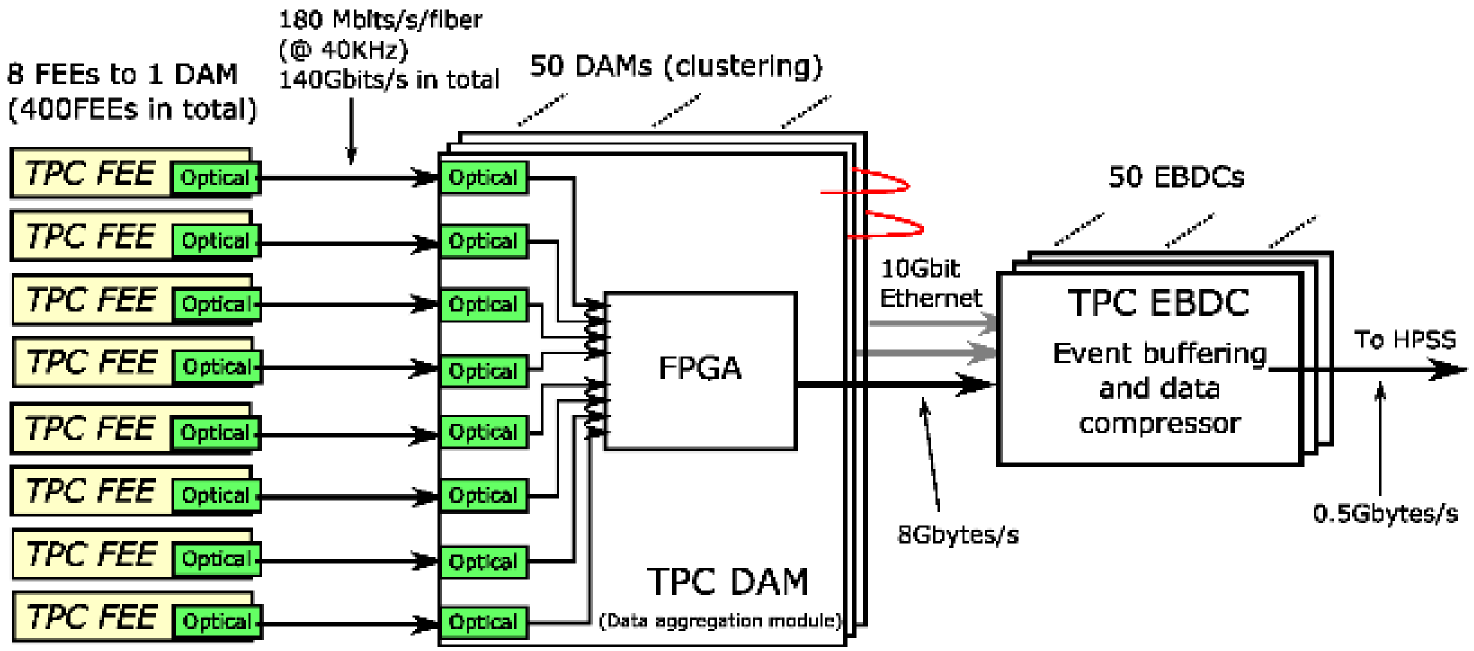
FEE (Frontend)

- Each FEE takes care of 256 inputs. We fabricate 400 FEEs
  - Use of SAMPA chips (SAMPA is shaper+ADC)
  - SAMPA takes care of 32 inputs. We put 8 SAMPAs on a board (4 SAMPAs on each side)
- FPGA is for receiving/distributing slow control and timing/clock
  - FPGA also collect digitized data from SAMPAs and format them for sending out (Optical)



Although our electronics designs are at a very early stage, we benefit significantly from the ongoing work in ALICE and STAR who are making the 1^{st} ever SAMPA implementations.

Electronics Design 2

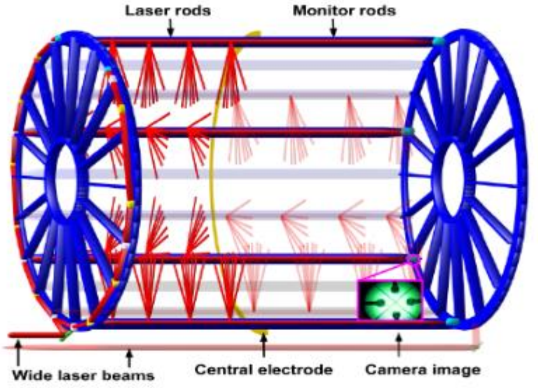


- SAMPA output effectively “buffered” onto optical, w/o trigger.
- TPC DAM provides pseudo-triggering mimicking multi-event buffering:
  - TPC drift time acts as “multi-event buffer”.
  - DAM module drops data if there is no trigger active (~4X data savings).
  - Late stage clustering of charge-sharing pads ala STAR reduces data footprint.

Support Systems

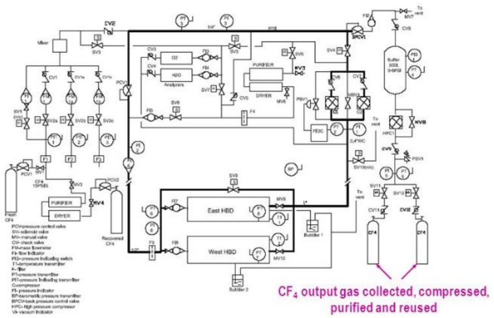
- Laser Systems
  - Laser pulses produce “on demand” ionization in the gas vital for testing & calibration.
  - sPHENIX members have long experience with lasers in the context of the EMCAL, but significantly less so wrt gas chambers.
  - Our cost/personnel/schedule for developing the laser system is based entirely upon private communications with Howard Wieman based upon ALICE experience.
- Gas Systems
  - sPHENIX has superb experience in high flow high purity gas systems for the PHENIX HBD wherein O_2 and H_2O contaminations were held continuously below 5 ppm.
  - Nonetheless, we also included advice from H. Wieman for the gas system specification.
- Cooling Systems
  - Liquid cooling is currently assumed.
  - sPHENIX TPC personnel have broad experience in liquid and gas cooling from multiple systems including but not limited to DC, RICH, HBD, MPC-EX, VTX.
  - Cost/personnel/schedule estimates nonetheless include advice from H. Wieman.<

ALICE Laser System

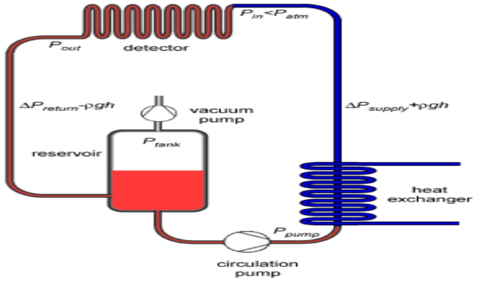


HBD Gas System

(Leonid Kotchenda, Rob Pisani, Carter Biggs)



ALICE Cooling System



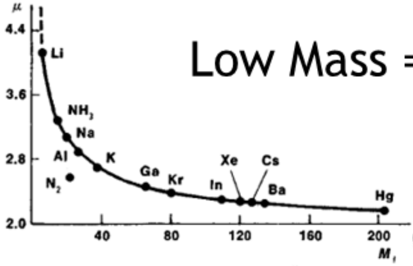
Technical Challenges 1: IBF

- Positive ions in the TPC volume create a space charge that distorts apparent hit point position.
- Techniques to minimize:
  1. Use a gas with a high ion mobility (Ne-Based)
  2. Low IBF Operating point (OK to reduce E-resolution)
  3. Move inner field cage back.
- Future R&D Possibilities (NOT ASSUMED!)
  1. Develop Gain==1 IBF shield.
  2. Install a Wieman grid.

  Ongoing R&D

Note: IBF is implemented in simulation as:
- A smear proportional to distortion
- A shift proportional to distoriion
- Proportionality constants from ALICE/STAR experience…

Low Mass = High Mobility



GEM Solution for ALICE

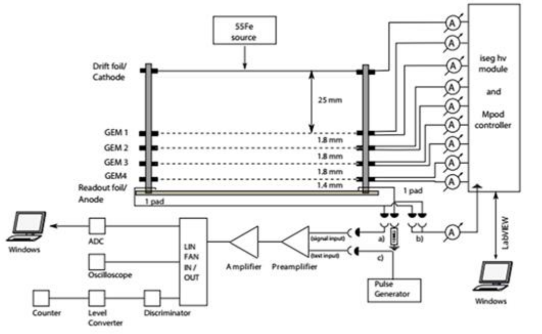
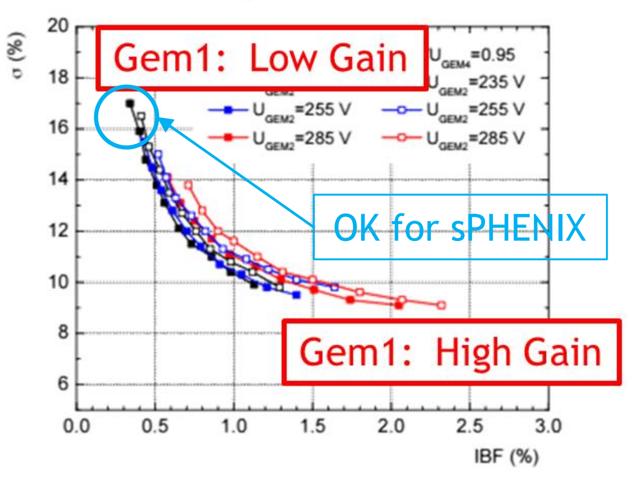
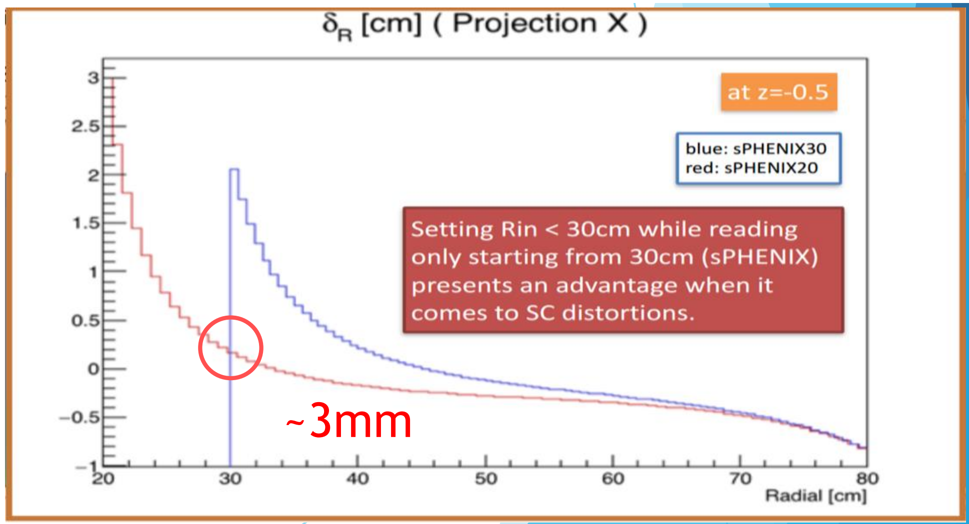


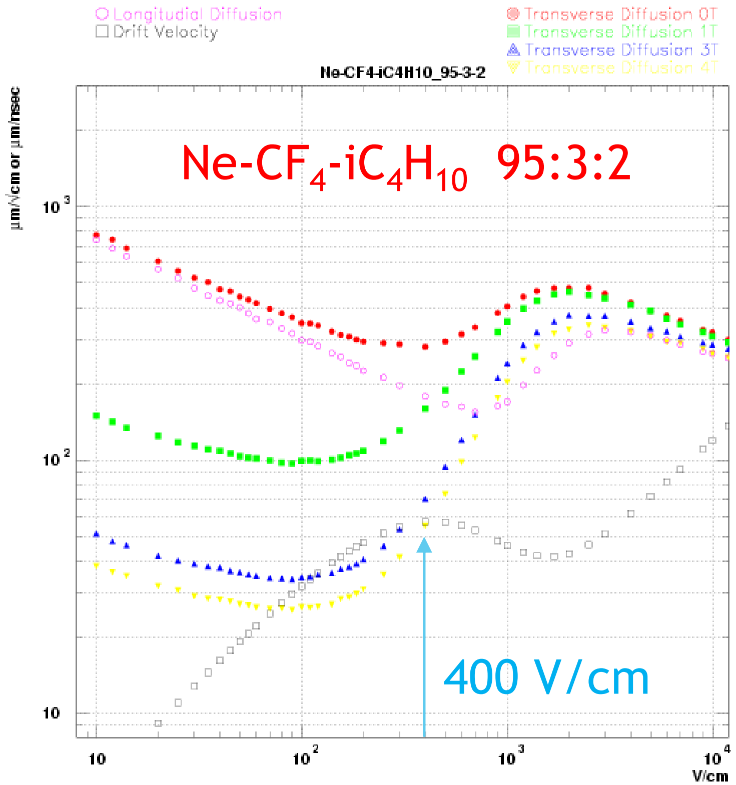
Figure 5.1: Sketch of the Munich quadruple GEM setup.





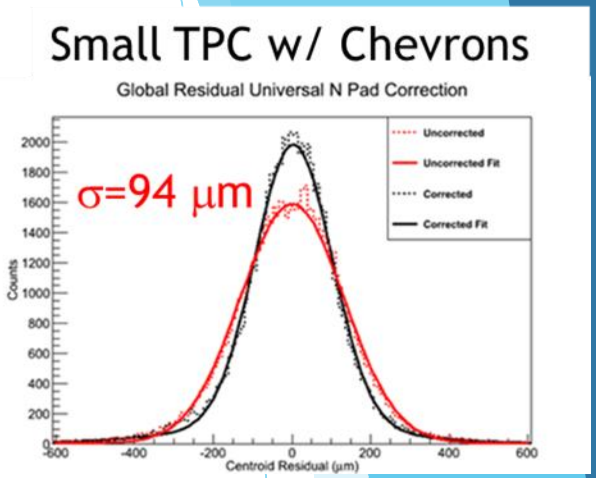
Note: Because of the 1.5 T field, the rdϕ distortion in sPHENIX is comparable to dr.

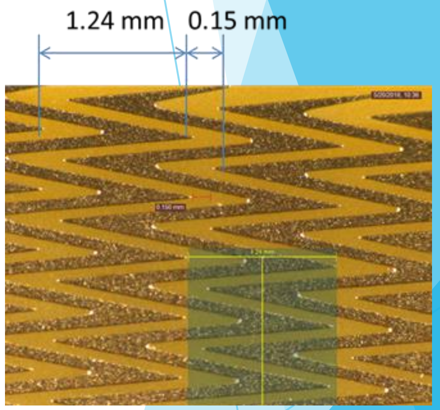
Technical Challenges 2: Resolution



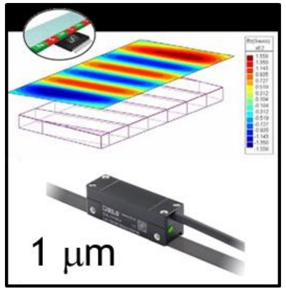
Gas Choice:
- Dominantly Neon, low space charge
- Low diffusion
- Plateau in v_{drift} (stability!)

- T2K: Ar-CF_4-iC_4H_{10}
  - 100 mm achieved for long TPC.
- "Ne2K": Ne-CF_4-iC_4H_{10}
  - VERY similar diffusion to T2K
  - VERY similar mobility to ALICE



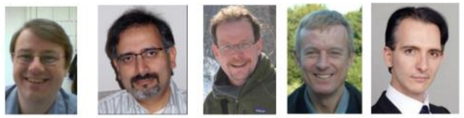


- Single point resolution <100 µm achievable.
- Charge transport challenging:
  - Gas Choice
  - Field Uniformity
    - In situ electrode position measurement (map) to 1 µm!



Collaborating Institutions and Technical Experience

Stony Brook University



Faculty

Postdocs

Grad Students

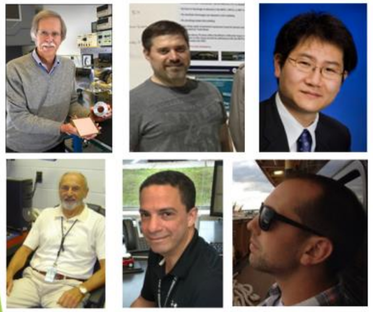
Electrical Engineer (retired)

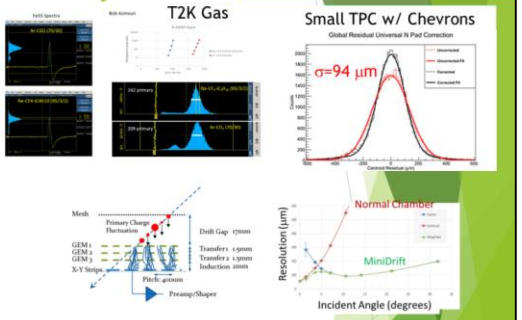
A steady stream of undergrads

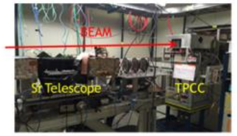
AGS experiments Tracking, PHENIX Tracking, PHENIX HBD, ILC TPC, generic TPC R&D

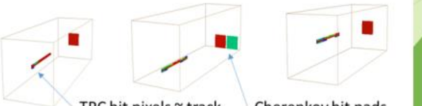
Brookhaven National Laboratory

AGS Tracking, PHENIX Tracking, LEGS TPC, generic TPC R&D



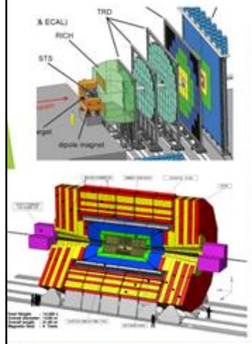






PNPI

PHENIX Tracking, ALICE muons, CMS, CBM, ...

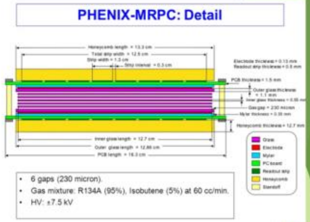


Vanderbilt University

Faculty

Postdoc

Grad Students

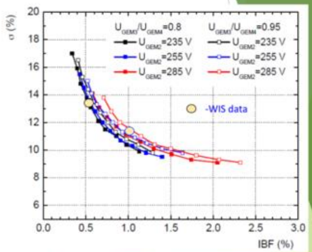


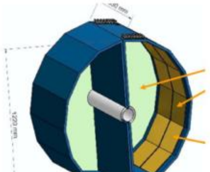
AGS experiments Tracking, PHENIX Tracking

Weizmann Institute of Science

Faculty

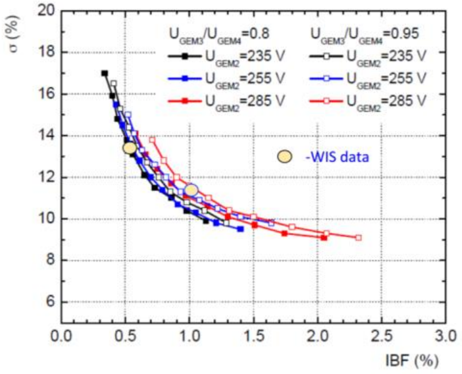
PHENIX Tracking, PHENIX HBD, generic TPC R&D





R&D to Date

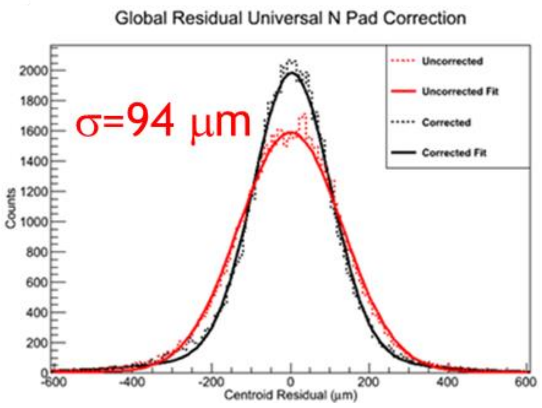
IBF results

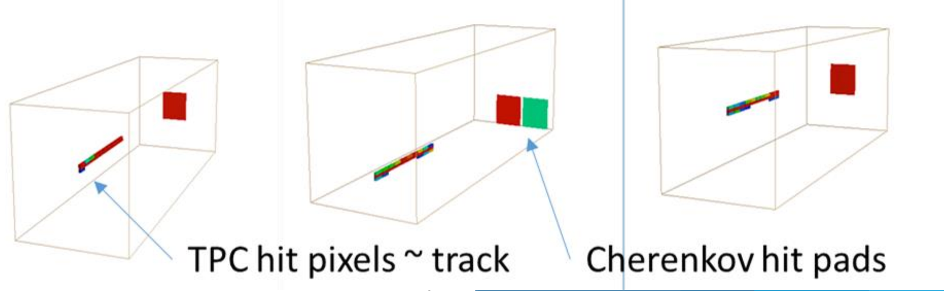


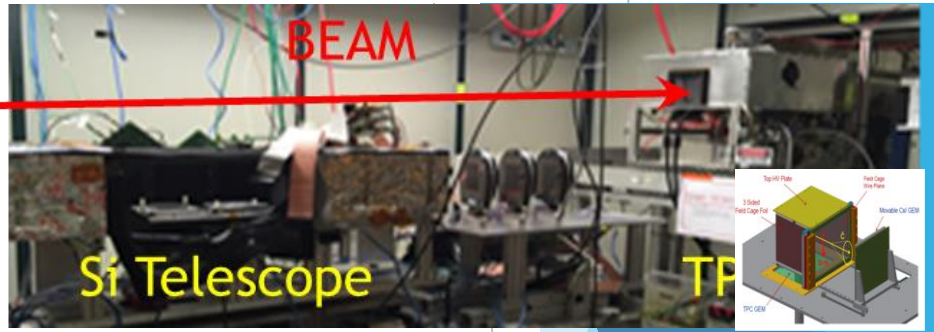
Element	Setup 1	Setup 2
Drift	0.4 kV/cm	0.4 kV/cm
GEM1	275 V	270 V
Transfer 1	4 kV/cm	4 kV/cm
GEM2	255 V	255 V
Transfer 2	2 kV/cm	2 kV/cm
GEM 3	270 V	275 V
Transfer 3	0.01 kV/cm	0.09 kV/cm
GEM 4	360 V	355 V
Extraction	4 kV/cm	4 kV/cm
Gain	2150	1910
Resolution	11%	13.5%
IBF	1%	0.55%

Vlad Peskov TPC meeting Aug 18,2016 10

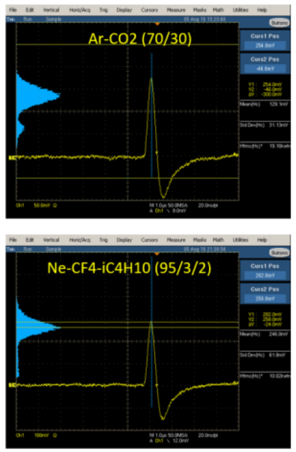
Small TPC w/ Chevrons





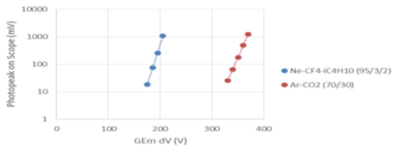


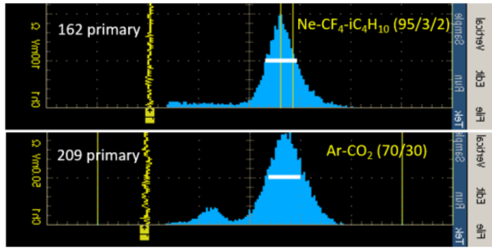
Fe55 Spectra

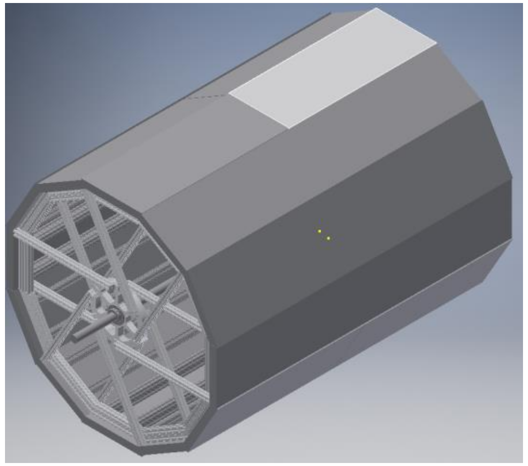


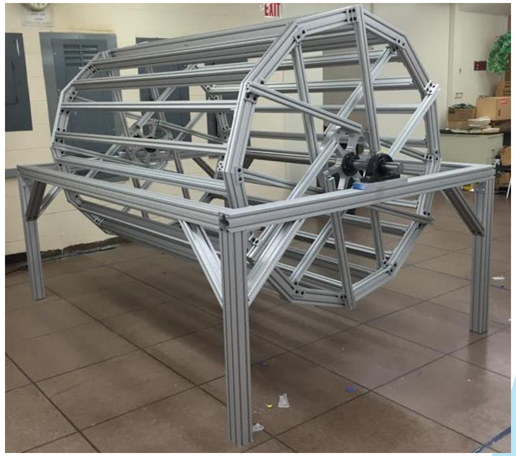
Bob Azmoun

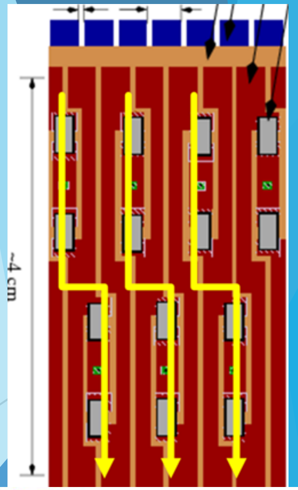
“Ne2K Gas”

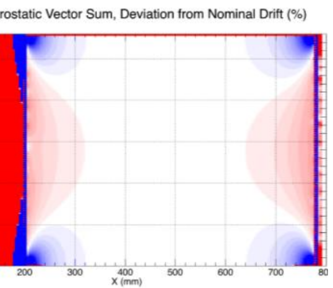


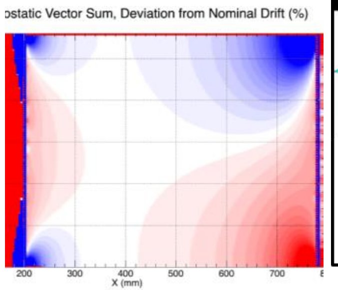


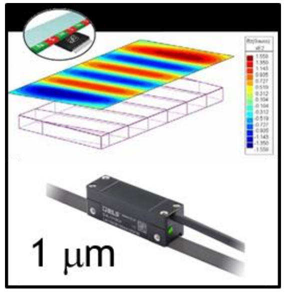


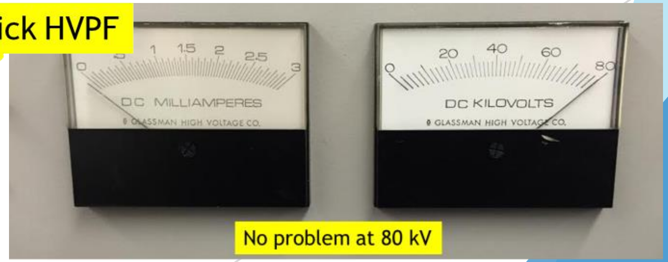










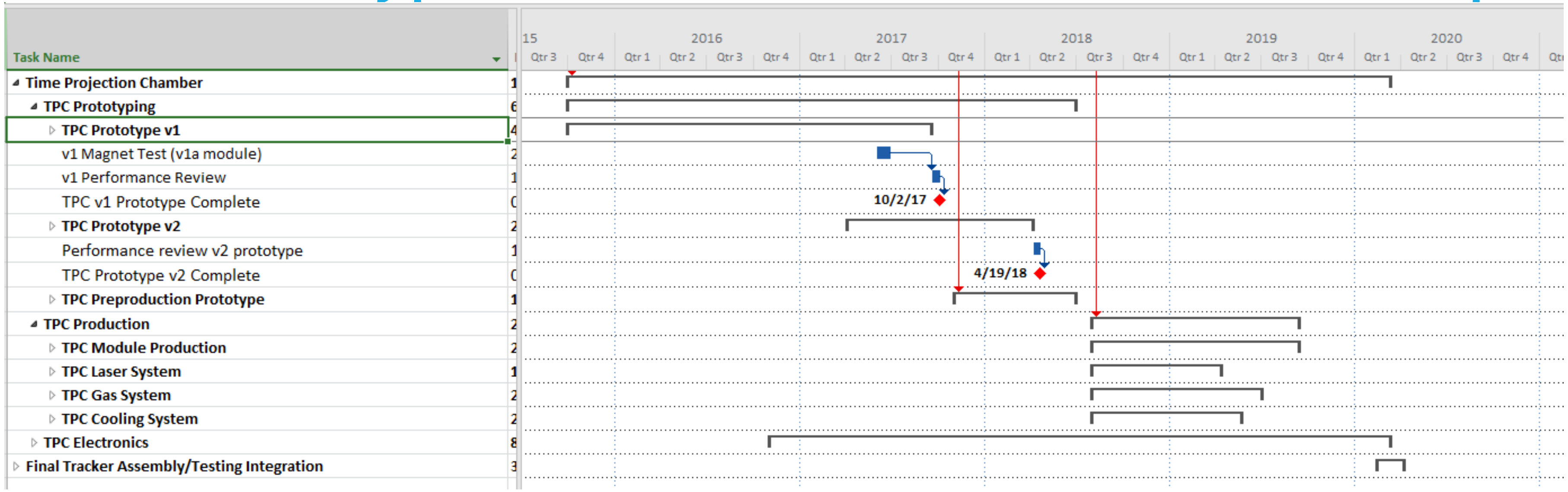


HVC Series

High Voltage Thick Film Chip Resistor

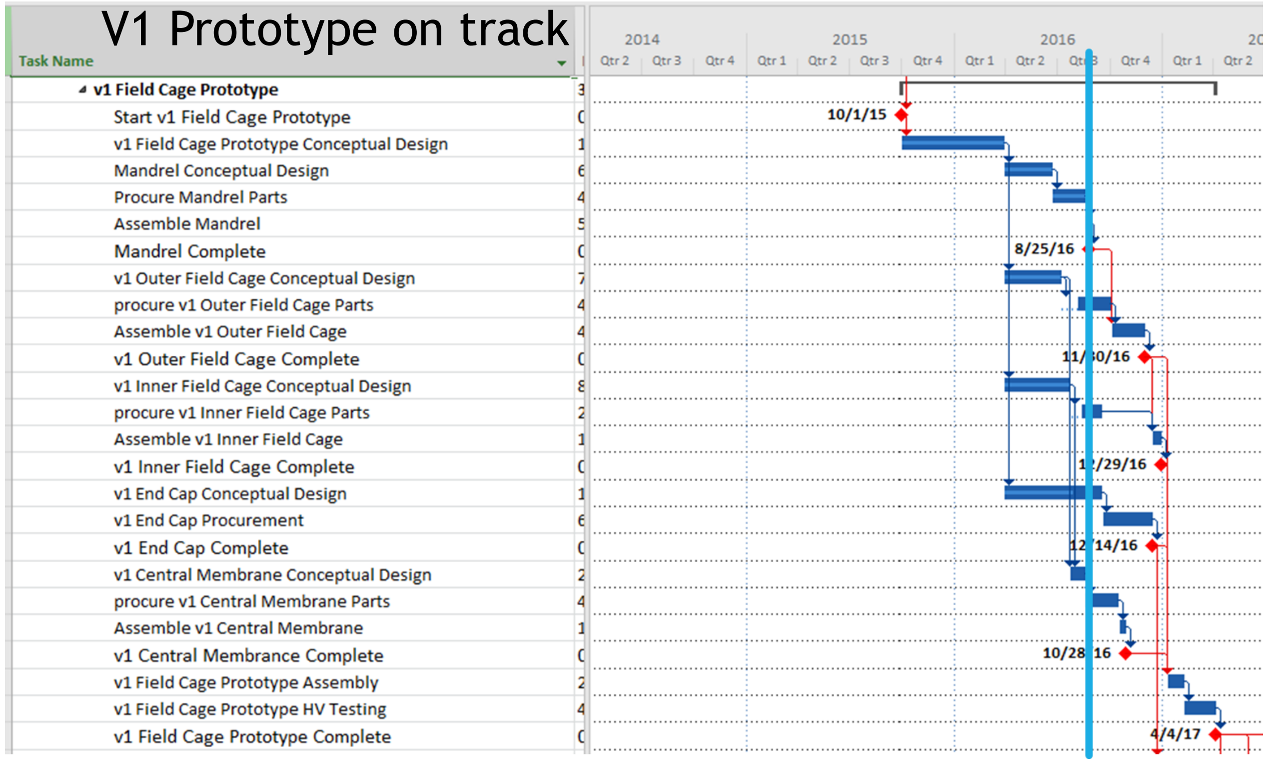
Features:
- Absolute voltage ratings up to 40,000 volts
- Ohmic values to 50G
- Available with wire bondable terminations
- Tight tolerances to 0.1%
- Utilizes fine film resistor deposition technology
- Superior pulse handling capabilities
- Low TCR to 25 ppm/°C
- Low VCR to 1 ppm/volt
- Very low noise
- Ultra high stability
- Custom sizes available
- Higher or lower resistance values may be available (contact factory)
- Standard HVC parts are unmarked
- RoHS compliant

R&D Prototype Plans between Now and Completion

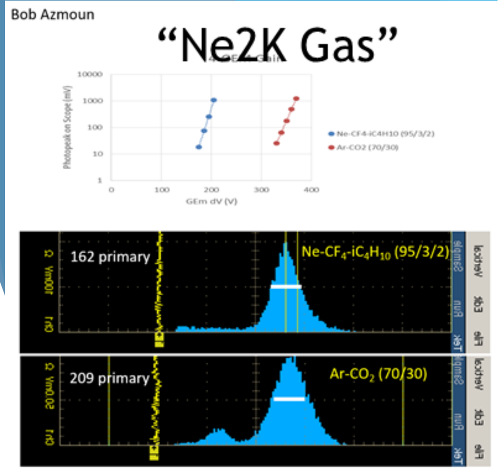


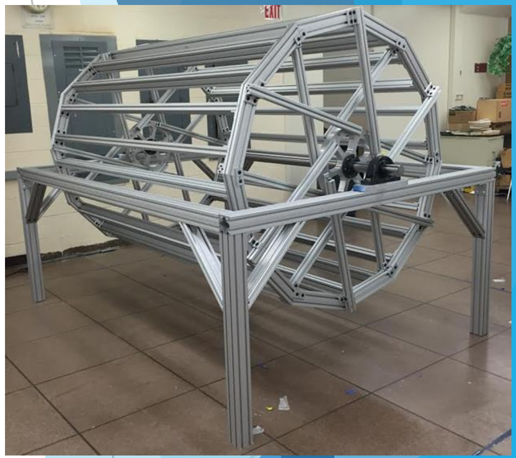
- v2 prototype
  - Advice from the Mini Review: 100% contingency on v1 success similar to rebuild at v2 stage.
  - v2 prototype now includes 2nd field cage as well as ever-advancing avalanche module designs.
- Pre-Production Prototype
  - Needs to not only test design of final module(s), but also ALL factories.
  - Schedule & cost updated to reflect 3 factories running in parallel: WIS, Vanderbilt, PNPI
- Schedule overlaps of prototyping stage driven by multiple factors:
  - v2 FIELD CAGE prototype design consideration does not have to wait for module tests.
  - Setup of factory floors for pre-production does not have to wait for v2 final test.

Project Status

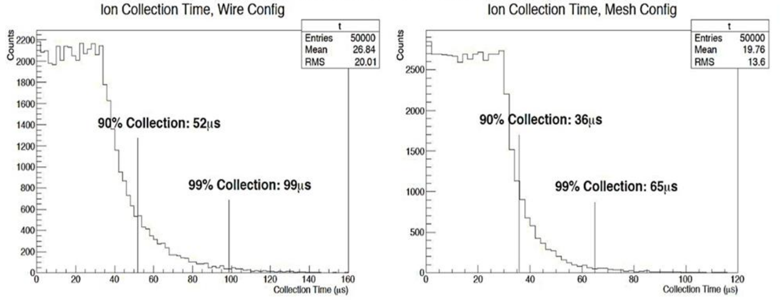


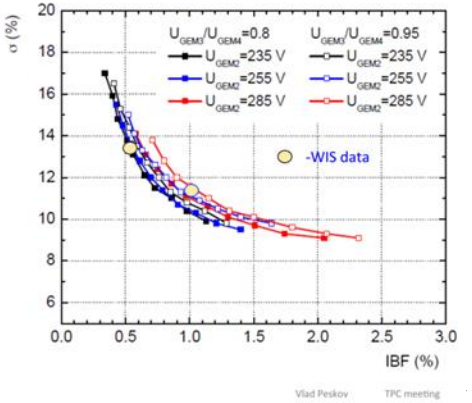
- Current Progress on track.
- Foam board arrived for mandrel.
- Nearly ready to begin v1 outer field cage
- R&D ongoing for pad plane segmentation.
- R&D ongoing for IBF.

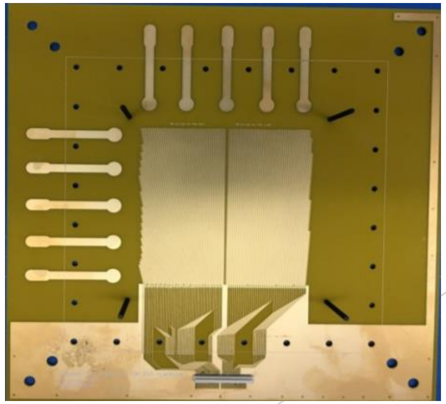


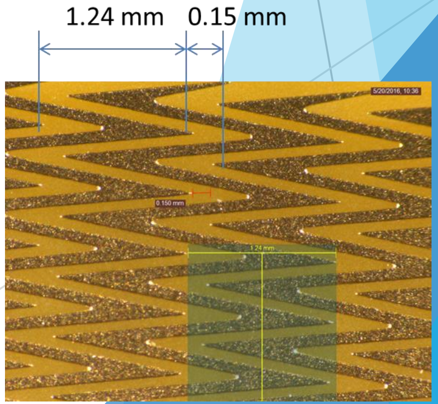


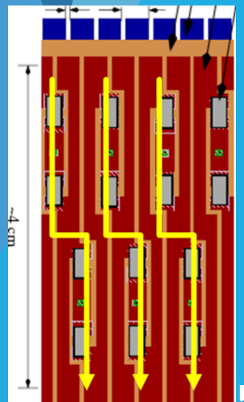
H. Wieman Grid simulation











Issues and Concerns

	Issue/Concern
SAMPA Chip	Timeline for chip production; integration w/ DAQ
Ion Back Flow	Resolution degradation due to space charge (less than 1st feared)
High Voltage	Single point of failure using solid for HV barrier
TPC Field Map	What is and do we achieve the desired uniformity/measurement
Data Volume for continuous readout.	Sees full collision rate (not just w/in event vertex); “Throttling” will be somewhat effective (4X)
Reconstruction of TPC→MAPS	Simulations indicate improvement using intermediate tracker.

Backups

Technical Challenges 1

- This challenges one's belief in silver linings!
- I know of no good that comes from positive ions in the drift volume.
- The ion mobility itself is easy to calculate:
  - Independent of field for all reasonable E_{drift}

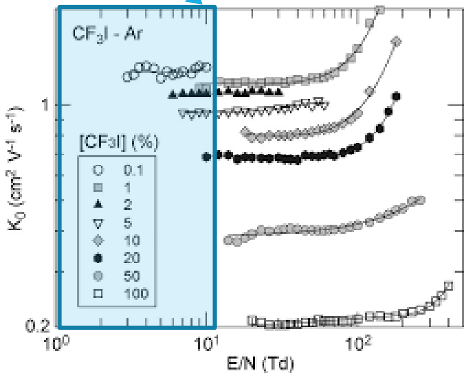
$$v_{ion\ drift} = KE$$

  - Easy to calculate for gas mixtures

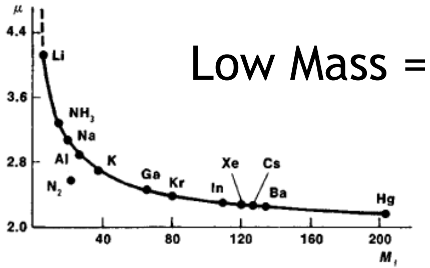
Resistors in parallel

$$\frac{1}{K_{TOT}} = f_1\frac{1}{K_{11}} + f_2\frac{1}{K_{22}}$$

Flat at all Reasonable Drift Fields

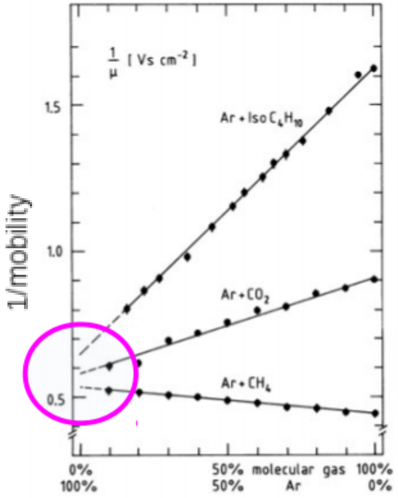


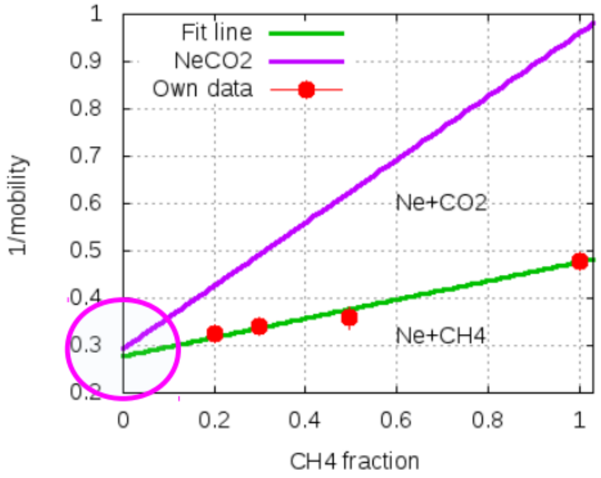
- ALICE Neon mixture helps (6X better than STAR)
- In my opinion, reducing ion mobility will likely force us to use a neon-based mixture.



Low Mass = High Mobility

Measurement of Blanc's Law





Gas	K ($\frac{cm^2}{Volt \cdot sec}$)	v_D ($E = 130\frac{V}{cm}$)	v_D ($E = 400\frac{V}{cm}$)
Ar	1.51	196	604
Ar-CH_4 90:10	1.56	203(STAR)	624
Ar-CO_2 90:10	1.45	189	582
Ne	4.2	546	1680
Ne-CH_4 90:10	3.87	503	1547
Ne-CO_2 90:10	3.27	425	1307(ALICE)
He	10.2	1326	4080
He-CH_4 90:10	7.55	981	3019
He-CO_2 90:10	5.56	722	2222
T2K	1.46	190(ILC)	584

Technical Challenges 2

- Ion Back Flow measurements are receiving attention as never before.
- Both Yale (EIC/ALICE) and Munich (ALICE) have performed extensive measurements.
- Universal (natural) trend emerges:
  - Since IBF from 1st GEM is ~100%, the IBF is controlled by GEM1 gain.
  - Fluctuations in 1st stage gain define limiting energy resolution.
- Gain stage has TUNABLE performance
  - Ion+Ion … low IBF
  - e+Ion … good E-resolution for PID.

ALICE does not have this luxury, but we do!

Quad-GEM Solution for ALICE

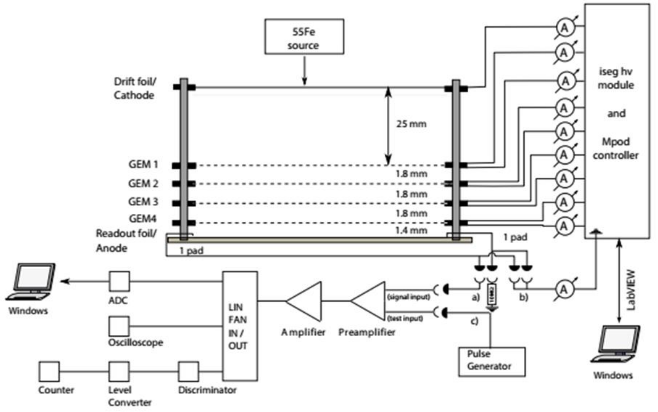
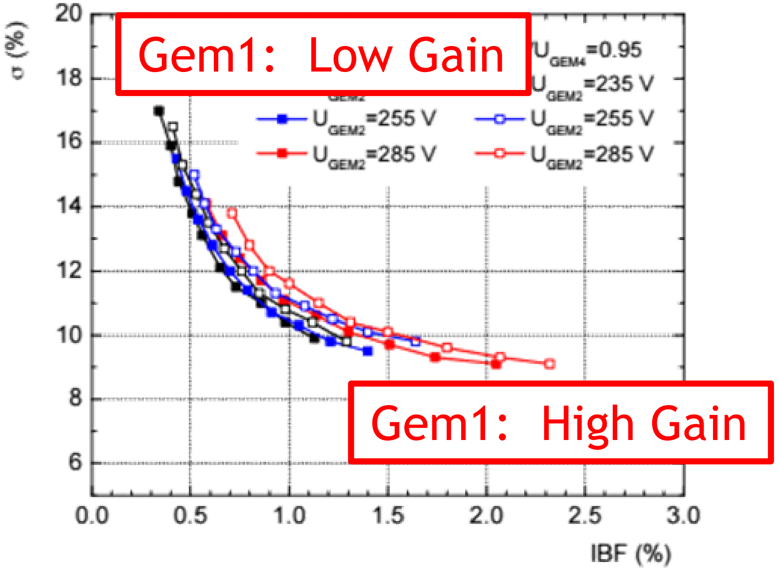
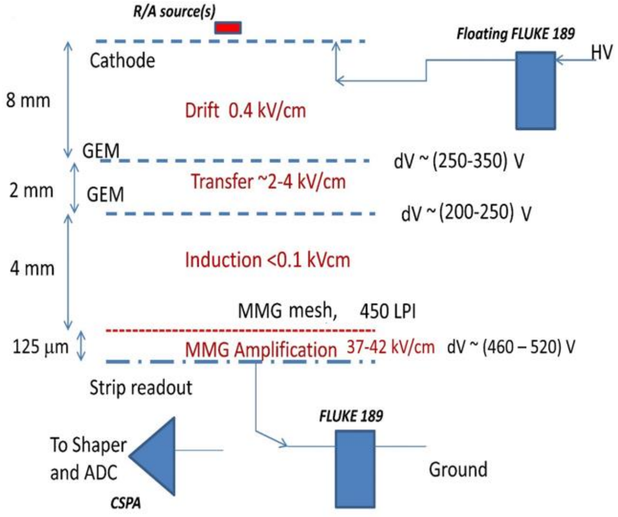
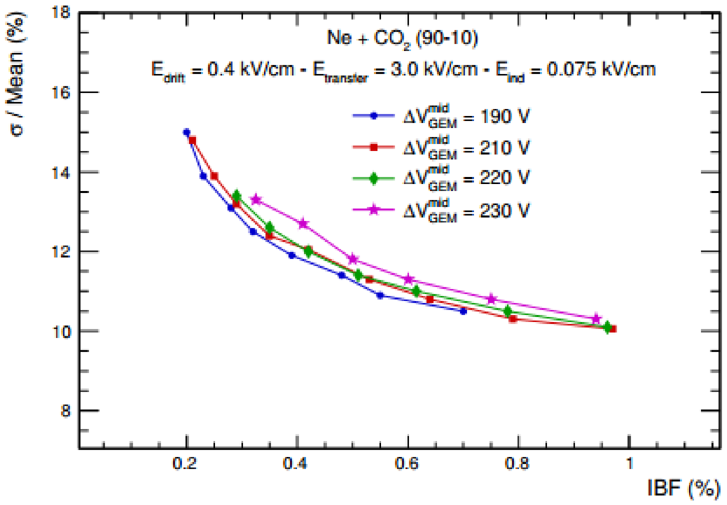


Figure 5.1: Sketch of the Munich quadruple GEM setup.



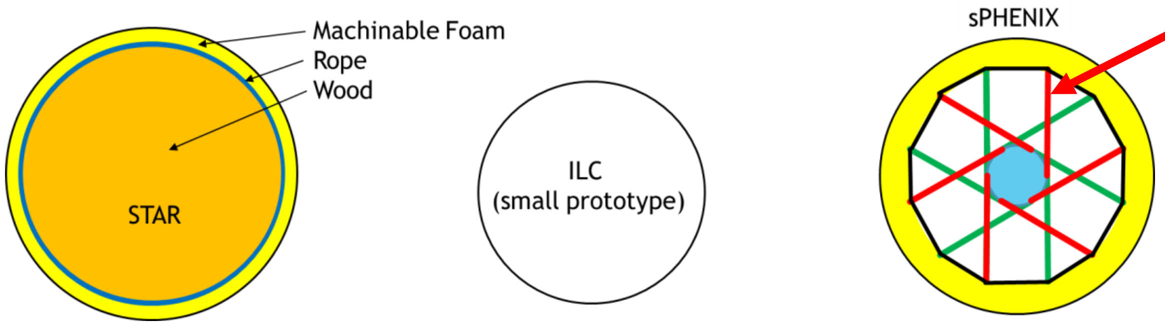
Dual-GEM + μMEGA Solution from Yale



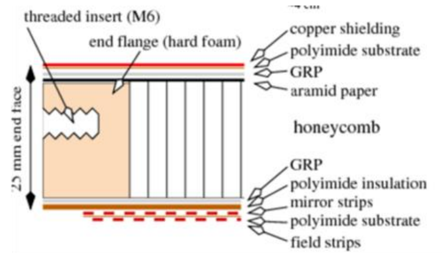


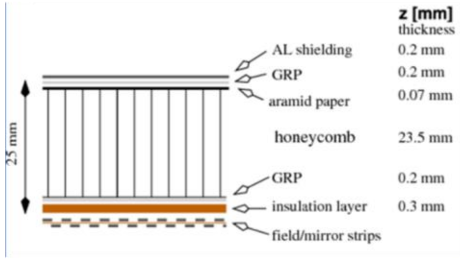
Mechanical Design 2

- Mainly from STAR/ILC (ALICE 3-layer design uses too much radial space).
- Manufacture technique hybrid between STAR and ILC.



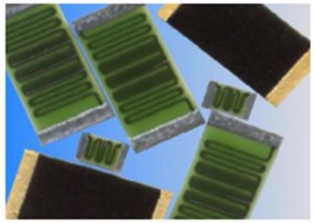
Disassemble spokes to release field cage.

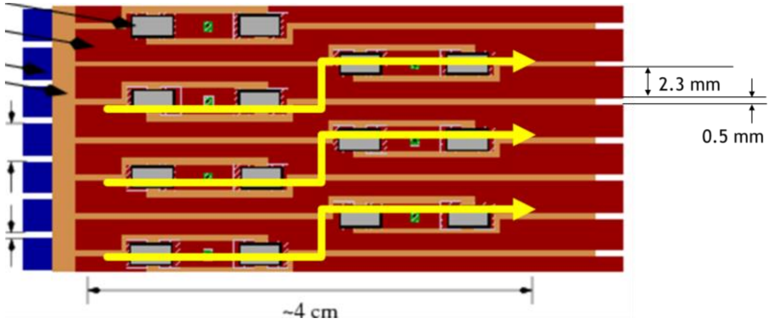


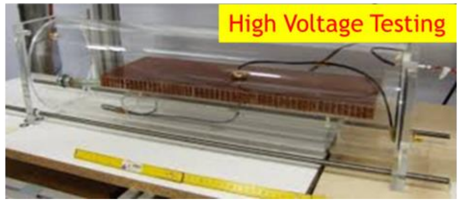


- Hold the main potential with SOLID, not gas (ala ILC).
- Use new form of resistors (HVPW) for reliability.

Stackpole Electronics, Inc.
Resistive Product Solutions

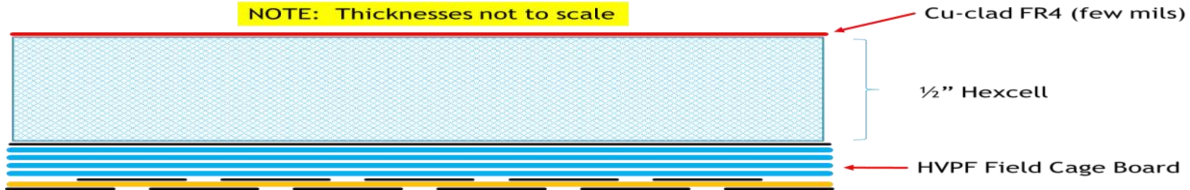






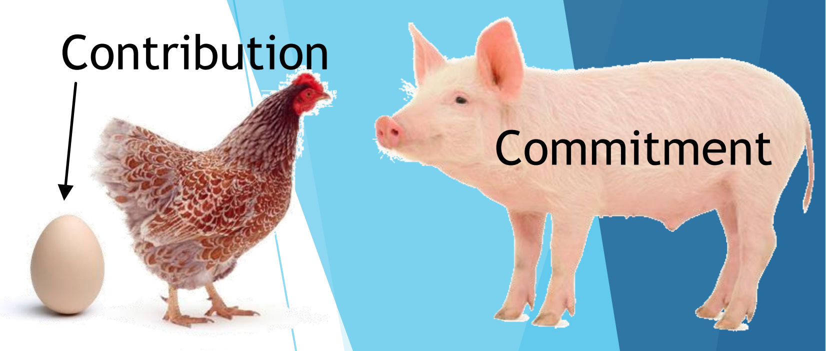
HVC Series
High Voltage Thick Film Chip Resistor

Features:
- Absolute voltage ratings up to 40,000 volts
- Ohmic values to 50G
- Available with wire bondable terminations
- Tight tolerances to 0.1%
- Utilizes fine film resistor deposition technology
- Superior pulse handling capabilities
- Low TCR to 25 ppm/ºC
- Low VCR to 1 ppm/volt
- Very low noise
- Ultra high stability
- Custom sizes available
- Higher or lower resistance values may be available (contact factory)
- Standard HVC parts are unmarked
- RoHS compliant



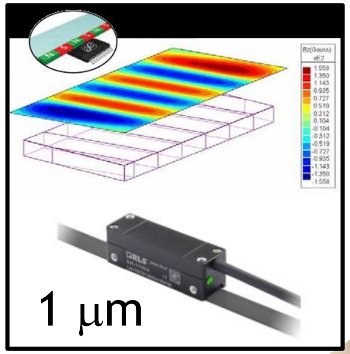
Mechanical Design 2

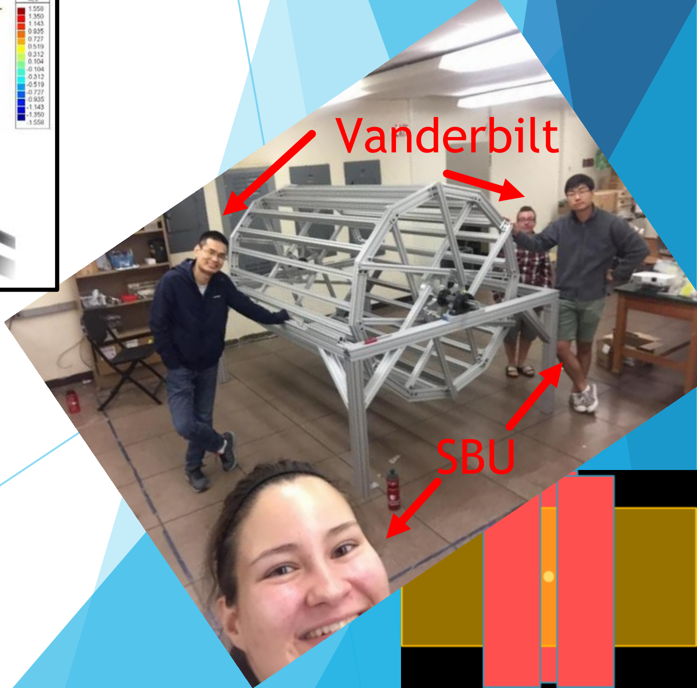
- Turn machinable foam down to desired radius.
- Pre-drilled holes allow section-by-section of the mandrel to become vacuum head to hold long “striped” kapton.
- Harmonic drive motors with 1 micron absolute position sensors position digital microscope for accurate electrode placement.
- Magnetic particle brake rollers deliver fresh kapton under uniform tension to wind up the insulating layer.
- Asymmetric honeycomb forms natural cylinder.
- Lathe action allows end pieces to be “faced off perpendicular”
- Spoke disassembly disengages field cage from mandrel.

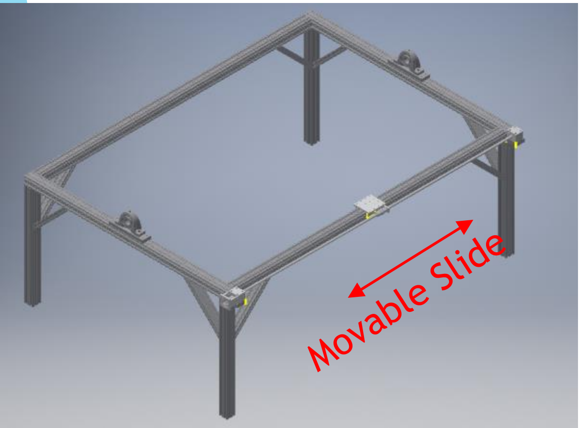


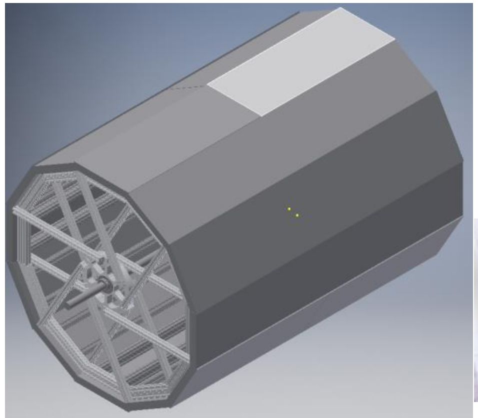
Item	Vendor	Total	Status
HVPF Boards	Sierra Express Circuits	$12,564.55	DELIVERED
8020 parts	McMaster-Carr	$7,959.44	DELIVERED
Clean Hood Motor Repair	Grainger	$554.75	DELIVERED
Tooling for Mandrel Table	McMaster-Carr	$774.82	DELIVERED
Optical readout for DVM (IBF)	Mouser	$79.99	DELIVERED
TOTAL		**$21,933.55**	

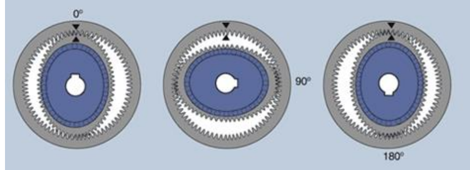
SBU-funds to kick off v1









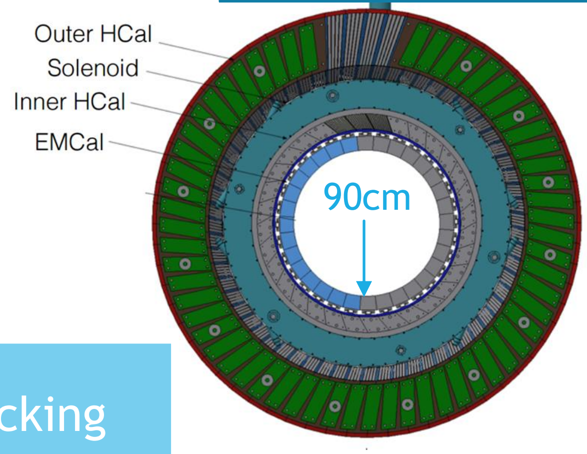


Backside routed for vacuum head

Technical Specifications

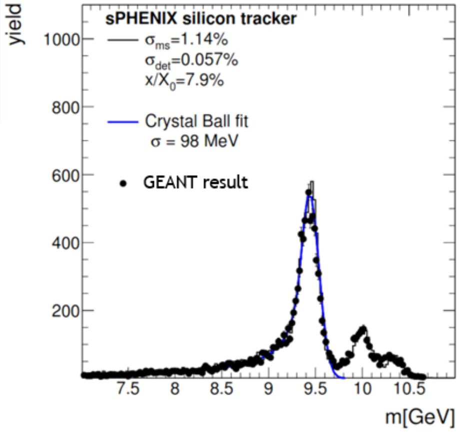
> "…we anticipate that the features and experience gained with this device might provide the basis for a "day-1" detector at a future EIC, independent of where the new facility will be sited. It is envisioned that this new collaboration will consider the possible evolution toward such a detector as part of its mission."
>
> --Berndt Mueller
>
> **Entertaining options requires more work but generates the necessary flexibility.**

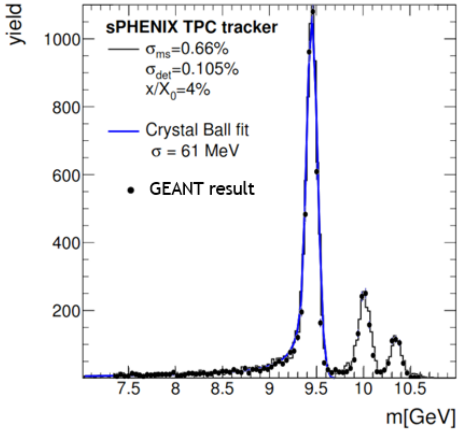
- Mechanical Constraints (magnet/EMCal-driven)
  - EMCal Mechanical constraint @ r=90cm.
  - Physics = coil aspect ratio: $|\eta| < 1.1$ or $Length \approx Diameter$
    - Current Tracker Confining Volume: Length = Diameter = 160cm.
- Physics program accomplished via two toughest constraints:
  - Mass resolution sufficient to resolve Upsilon States.
    - $\boldsymbol{\sigma_m < 100\ \frac{MeV}{c^2}\ @\ m \approx 9\ \frac{GeV}{c^2}}$ ← Outer Tracking
  - DCA Resolution sufficient for tagging heavy flavor secondary vertices.
    - $c\tau(D) = 123\ \mu m;\ \ c\tau(B) = 457\ \mu m$
    - $\boldsymbol{\sigma_{DCA} < 100\ \mu m}$ ← Inner Vertex
- Environmental constraints:
  - Central Au+Au multiplicity @ full RHIC Energy.
  - Full RHIC-II Luminosity (100 kHz raw, 15 kHz w/in vertex)



Mechanical Constraint

Physics Constraint





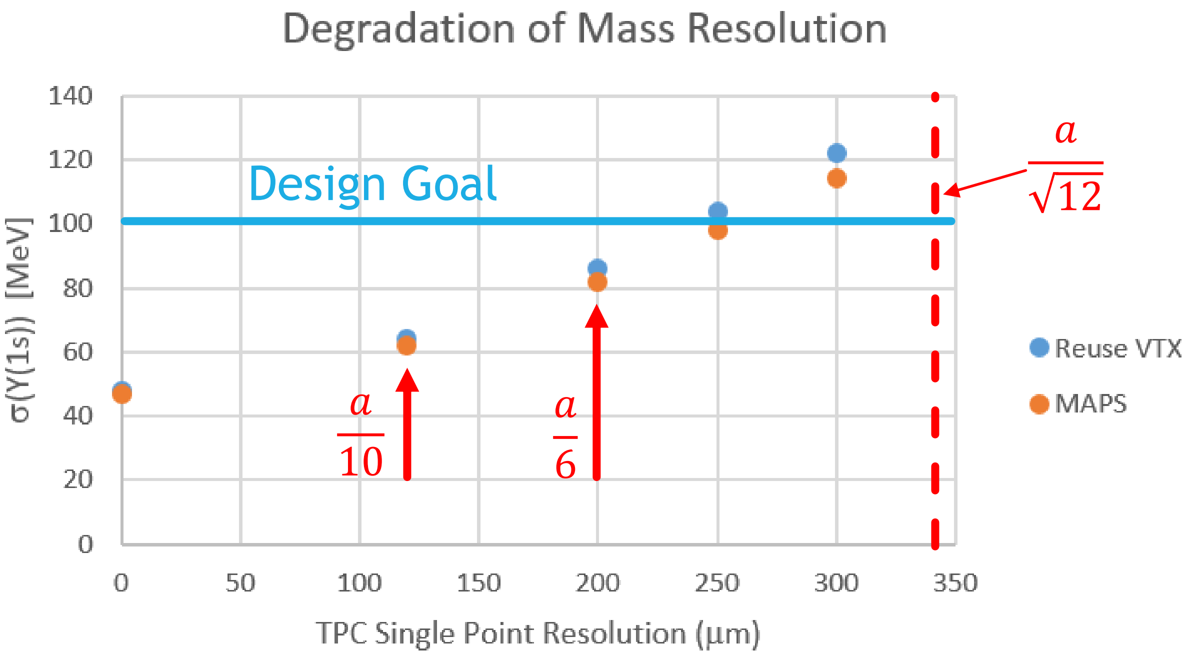
Design Drivers

Reference Option

Station	Layer	radius (cm)	pitch (μm)	sensor length (cm)	depth (μm)	total thickness X_0%	area (m^2)
Pixel	1	2.4	50	0.425	200	1.3	0.034
Pixel	2	4.4	50	0.425	200	1.3	0.059
S0a	3	7.5	58	9.6	240	1.0	0.18
S0b	4	8.5	58	9.6	240	1.0	0.18
S1a	5	31.0	58	9.6	240	0.6	1.4
S1b	6	34.0	58	9.6	240	0.6	1.4
S2	7	64.0	60	9.6	320	1.0	6.5

- In many ways, a multiple-scattering limited spectrometer is desirable; robust against:
  - Single point resolution.
  - Alignment.
  - Detector "creep"
- The design must maintain detector thickness spec. in the middle layer (dominant contributor to the sagitta determination).
- Mass resolution (currently ~6% better than required) will degrade as $\sqrt{\frac{x}{\chi_0}}$ of the S1 layer and improve as $\frac{1}{R}$ (radius of S2).
- The thickness of S1 determines the over-all size, R, and the cost (≈ R^2).
- We can tolerate a ~12% increase in the S1 thickness in the current design spec.

Hybrid Tracker Option



- The Upsilon mass width for the hybrid setup is influenced by the single point resolution.
- Current calculations assume an RMS resolution of 1/10 the pad size ($\frac{a}{10}$).
- The hybrid system will meet the design goal with an RMS resolution as bad as 250 μm.

Additional Design Drivers for TPC

- The hybrid option will benefit from the development of the ALICE upgrade detector(s).
- The list of considerations necessary to realize the hybrid option is nonetheless significant.
- More detail will be available in the afternoon session.
- Here we summarize some of the challenges facing our design.

	Comment 1	Comment 2
Chevron Pads	Good charge sharing for low diffusion gasses	Asserts a (correctable) diff. non-linearity
GEM gain stages	High rate capable (vs wire chamber)	Gain uniformity and drift; longevity
SAMPA Chip	TPC-specific chip, Continuous readout	ALICE Upgrade
Ion Back Flow	Tunable IBF vs dE/dx resolution	ALICE Upgrade
High Voltage	Known solids capable w/ safety margin.	Solids introduce single point failure.
Diffusion	Small diff improves resol, collection time	Diff assists spreading charge over pads.
Electron v_D	Fast lowers stacked evts; plateau desirable.	Slow lowers “voxel occupancy”
Noble Gas	Ar mix: nice plateau; low field; low ion mobility (therefore lots of space charge)	Ne mix: much higher ion mobility, no plateau, high V_{CM}
dE/dx	Not a driving feature for heavy ion program	Critical for EIC use

More work required to prove viability of hybrid design.

L2 Project Scope

13		1.3.2	⊟ Pixel Detector
14		1.3.2.1	⊞ Pixel Design
29		1.3.2.2	⊞ Pixel Production

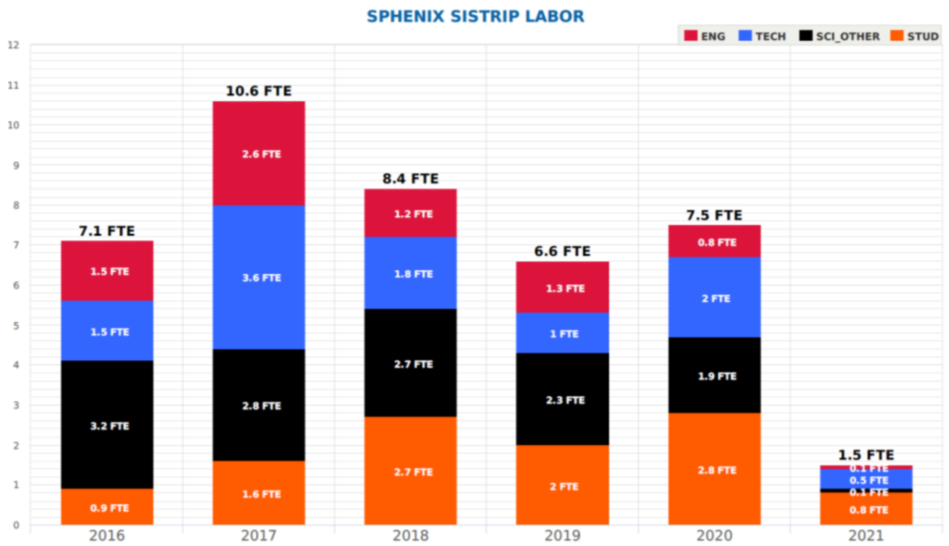
53		1.3.3	⊟ Outer SiStrip Detector
54		1.3.3.1	⊞ Outer SiStrip Design (Mech and system)
71		1.3.3.2	⊞ SiStrip Prototyping
133		1.3.3.3	⊞ Outer SiStrip Production
181		1.3.3.4	⊞ SiStrip Electronics

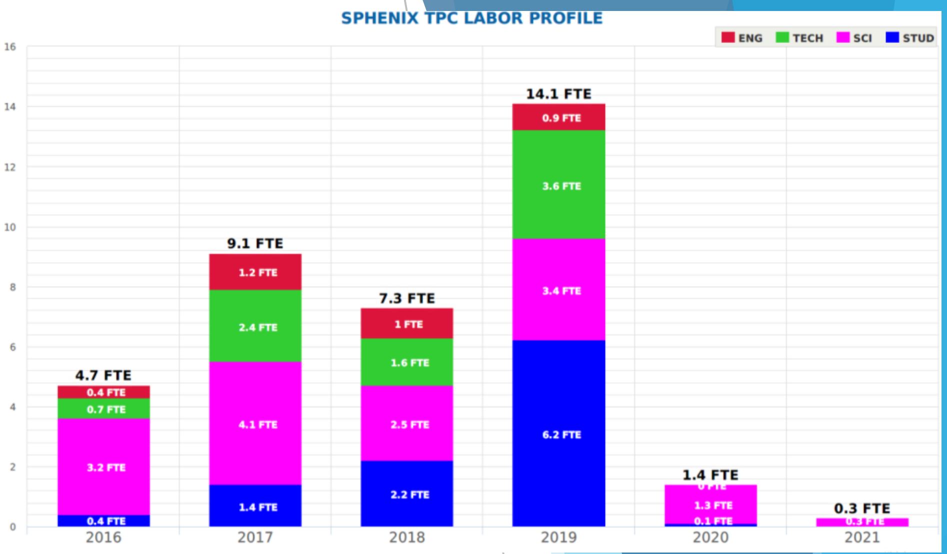
267		1.3.4	⊟ Time Projection Chamber
268		1.3.4.1	⊞ TPC Design
279		1.3.4.2	⊞ TPC Prototype
317		1.3.4.3	⊞ TPC Production
361		1.3.4.4	⊞ TPC Electronics

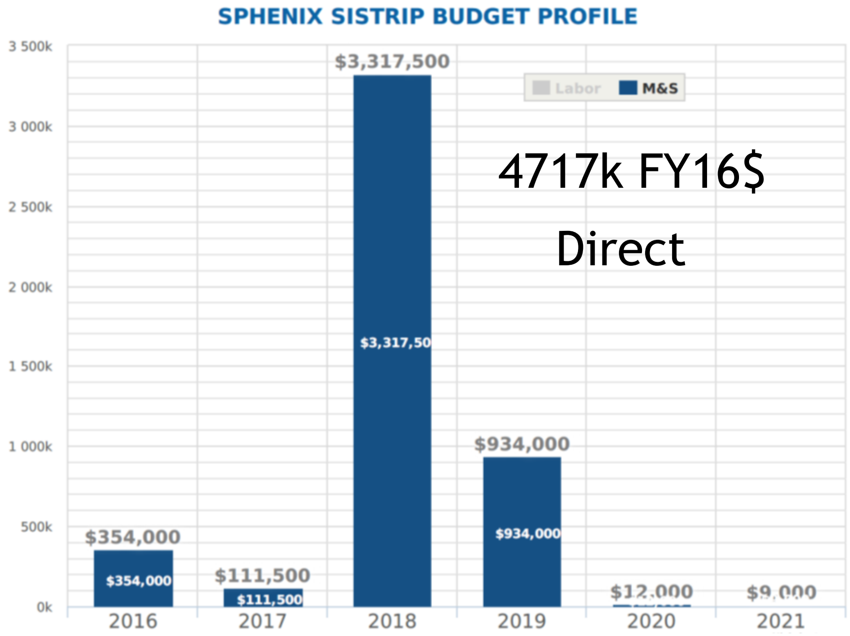
- These charts indicate the L2 items of the project scope for each detector option.

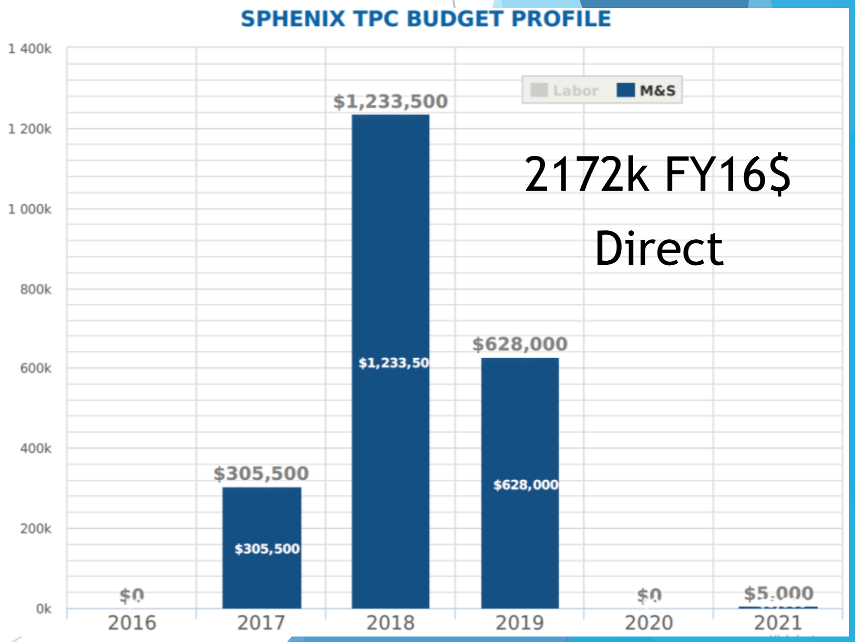
Resource/Cost Drivers

- Costs here are limited to the outer tracker options.
- Details on the inner tracker options will be presented in the afternoon breakout sessions.







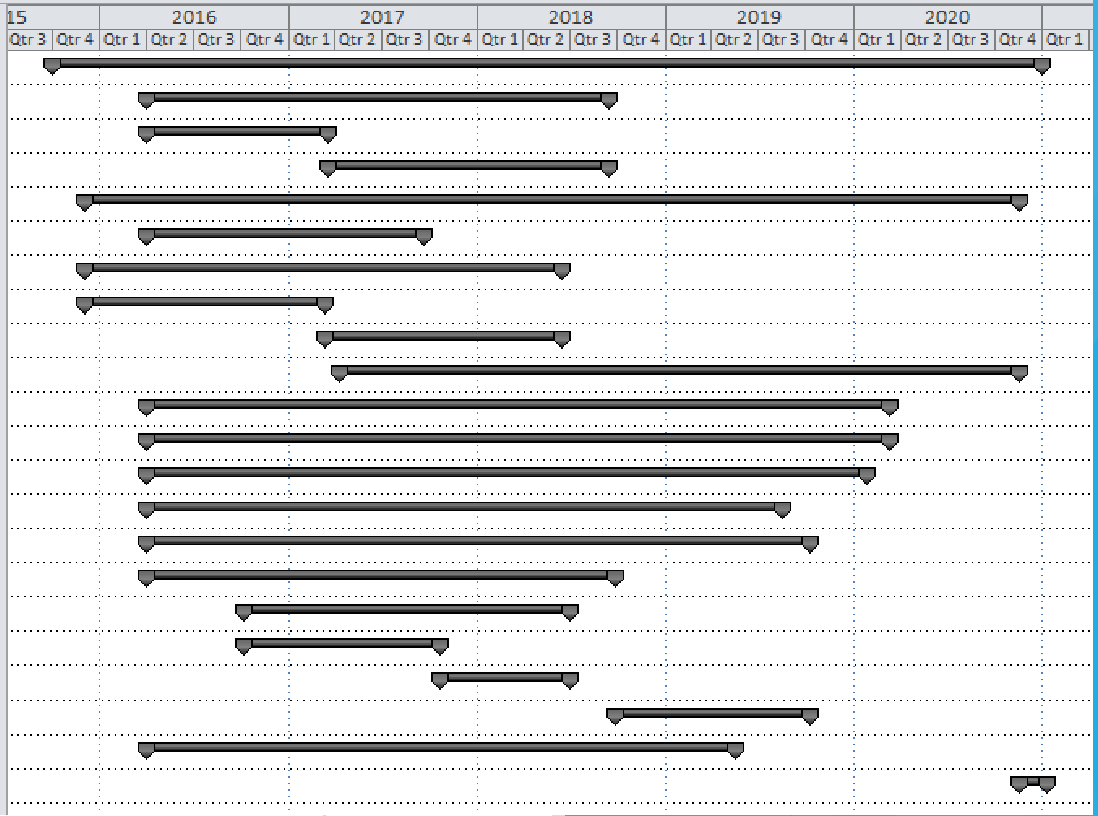


Time Projection Chamber

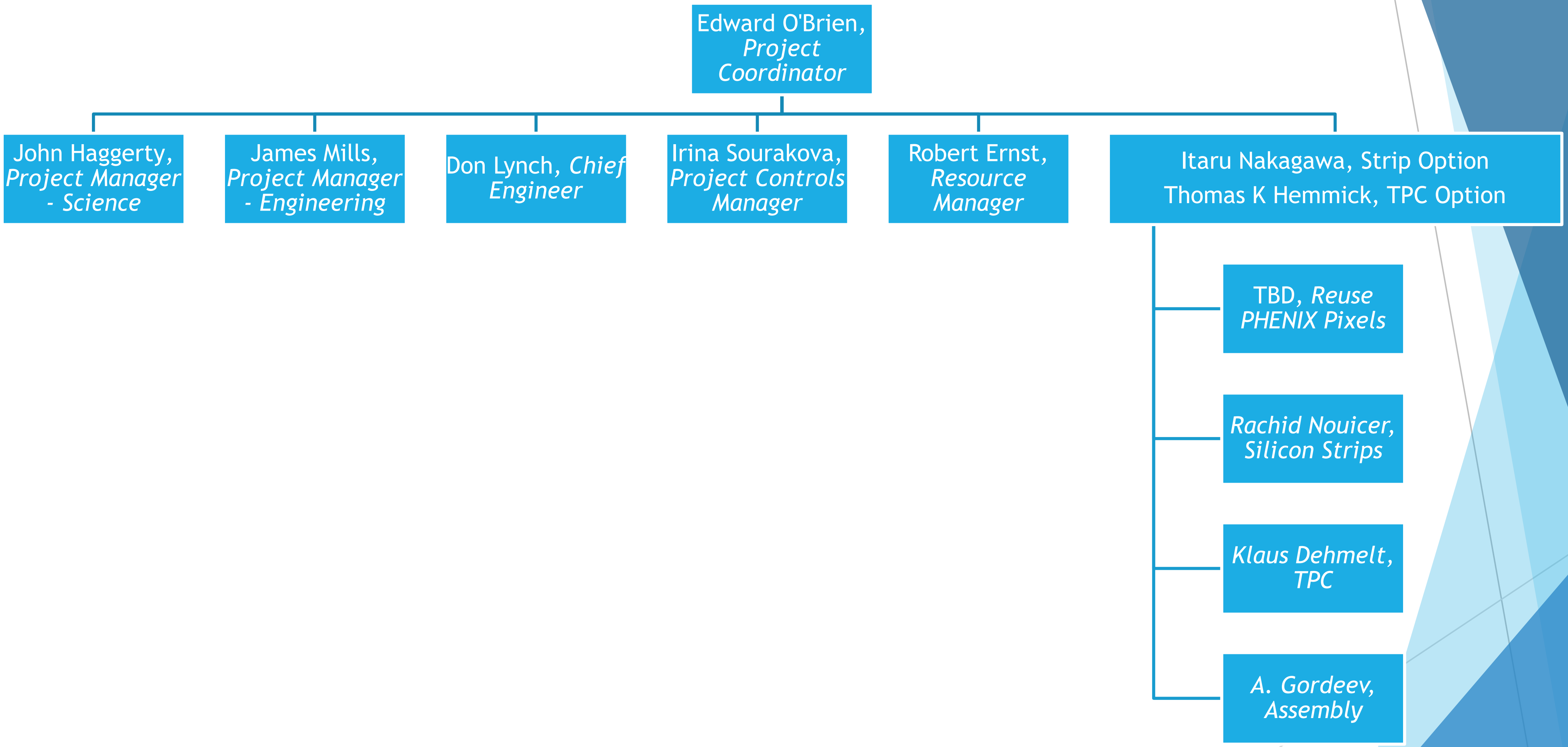
Schedule Drivers

- Technology decision needs to be made sometime in early to mid 2017 though it could easily be driven by a successful receipt of outside funding
- SiStrip: Sensor production and ladder, stave assembly drive the schedule
- TPC: Design and prototyping drive the schedule if one is to be ready to build in Jul 2018.

WBS	Task Name	Duration	Start	Finish
1.3.1	+ Tracker Management	1306 days	Thu 10/1/15	Wed 12/30/20
1.3.2	− Pixel Detector	614 days	Fri 4/1/16	Fri 9/14/18
1.3.2.1	+ Pixel Design	239 days	Fri 4/1/16	Thu 3/16/17
1.3.2.2	+ Pixel Production	375 days	Fri 3/17/17	Fri 9/14/18
1.3.3	− Outer SiStrip Detector	1235 days	Fri 12/4/15	Mon 11/16/20
1.3.3.1	+ Outer SiStrip Design (Mech and system)	369 days	Fri 4/1/16	Wed 9/20/17
1.3.3.2	− SiStrip Prototyping	630 days	Fri 12/4/15	Wed 6/13/18
1.3.3.2.1	+ SiStrip Prototype v2	315 days	Fri 12/4/15	Fri 3/10/17
1.3.3.2.2	+ SiStrip Preproduction Prototype	315 days	Mon 3/13/17	Wed 6/13/18
1.3.3.3	+ Outer SiStrip Production	900 days	Mon 4/10/17	Mon 11/16/20
1.3.3.4	− SiStrip Electronics	981 days	Fri 4/1/16	Tue 3/10/20
1.3.3.4.1	+ SiStrip Sensor ASIC	981 days	Fri 4/1/16	Tue 3/10/20
1.3.3.4.2	+ SiStrip ROC	951 days	Fri 4/1/16	Mon 1/27/20
1.3.3.4.3	+ SiStrip Front End Module	841 days	Fri 4/1/16	Wed 8/14/19
1.3.4	− Time Projection Chamber	880 days	Fri 4/1/16	Wed 10/9/19
1.3.4.1	+ TPC Design	620 days	Fri 4/1/16	Mon 9/24/18
1.3.4.2	− TPC Prototype	432 days	Wed 10/5/16	Fri 6/29/18
1.3.4.2.1	+ TPC Prototype v2	261 days	Wed 10/5/16	Fri 10/20/17
1.3.4.2.2	+ TPC Preproduction Prototype	171 days	Mon 10/23/17	Fri 6/29/18
1.3.4.3	+ TPC Production	260 days	Mon 9/24/18	Wed 10/9/19
1.3.4.4	+ TPC Electronics	780 days	Fri 4/1/16	Thu 5/16/19
1.3.5	+ Final Tracker Assembly/Testing Integration	35 days	Mon 11/16/20	Mon 1/11/21



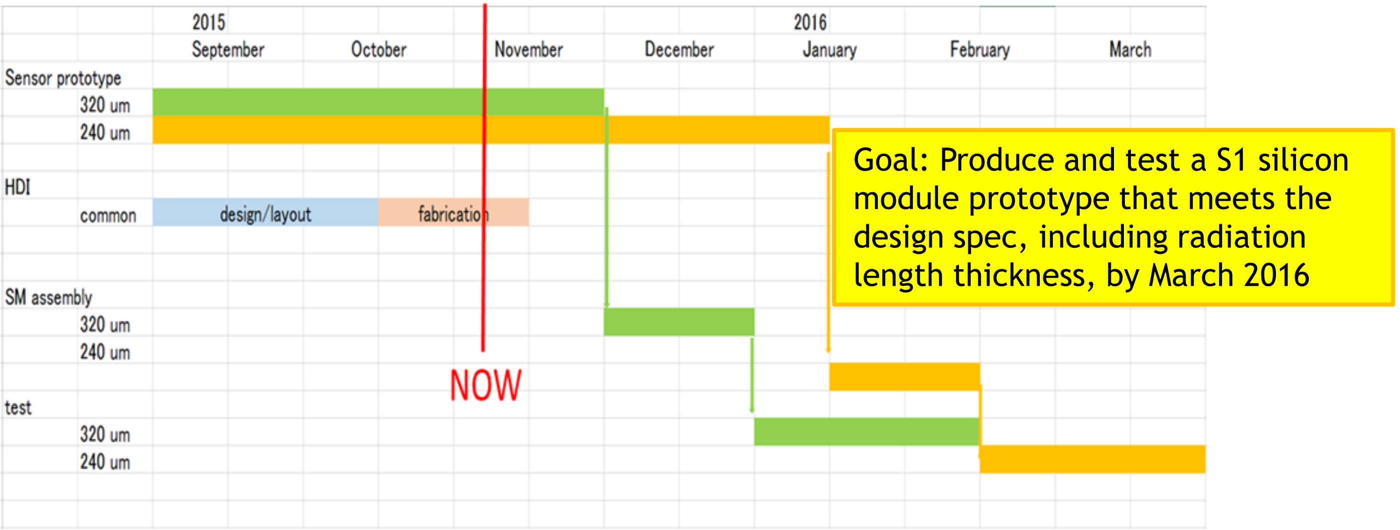
Organization



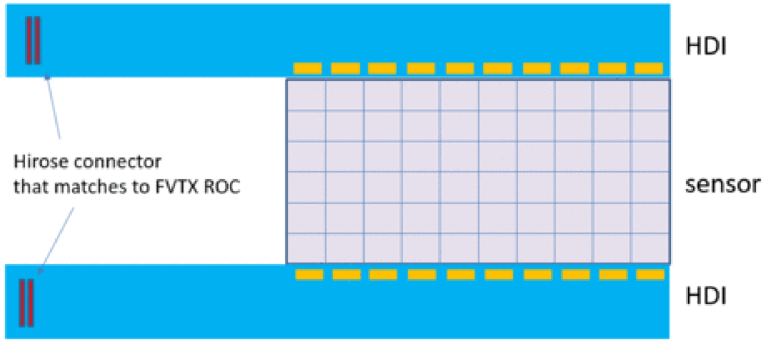
Organizational Chart depends upon technology choice.

Technical/Project Status

S1 Silicon module prototype

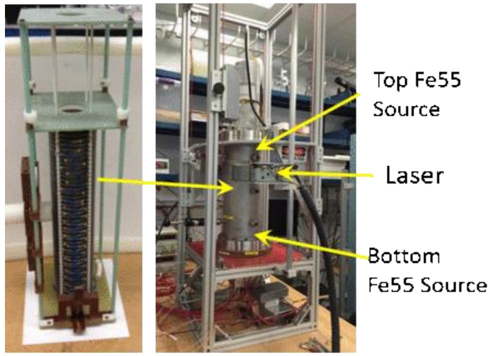


- Sensor for S2
  - 96 mm x 92.16 mm
  - 320 μm thick
  - AC coupled
  - 60μm x 8mm ministrips
  - 128x24 readout channels
- 5 sensors, March 2015
  - No NG channels or strips
  - Vfd = 50 V
  - Vbreakdown > 250V (>500V for two)
- All 5 sensors are now at BNL for testing

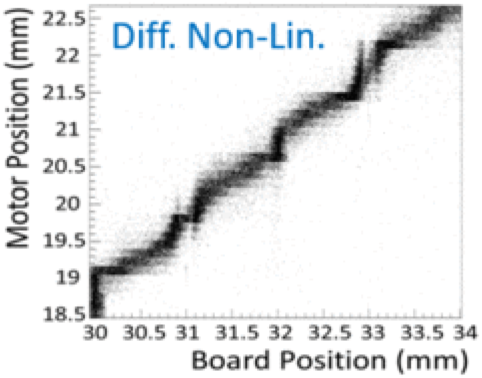


TPC R&D (ongoing from EIC)

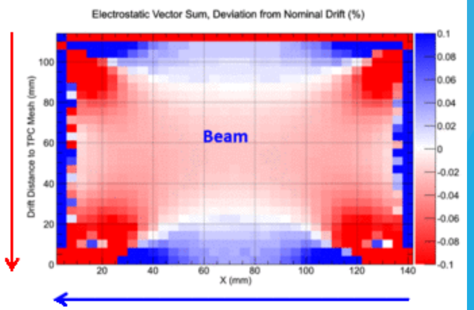
Apparatus



Results



Simulation



- Novel segmentation schemes
- Pad plane response <100 μm w/ 2mm pads.
- Full Gas characterization:
  v_d, charge attachment, ion mobility, avalanche spread.
- Test beam & cosmic tracking.

Issues and Concerns

Summary

- Consistent with the charge of maintaining long term viability of the tracking technology we are purposely developing competing alternatives:
  - Inner Vertex Detector
    - Reuse PHENIX pixels
    - MAPS technology
  - Outer Tracker
    - Silicon Strip Detector
    - TPC
- All of these technologies have been shown to meet the physics requirements for heavy ion collisions with varying performance, risk, and utility for longer term use.